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Høgskolen i Buskerud
Avdeling for Teknologi

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Emnekode: SFHO-3200

Prosjektnavn
Kompakt Fly-By-Wire System
Compact Fly-By-Wire System

Utført i samarbeid med: Equator Aircraft Norway.

Ekstern veileder: Knut Brødreskift

Sammendrag: Vi fikk en oppgave av Equator Aircraft Norway, den gikk ut på å utvikle et elektronisk styringssystem til deres nye prototype; P2 Excursion. Vi skal kunne styre alle styreflatene kun ved hjelp av en tre akse joystick, slik at ror-pedalene som er vanlige i småfly i dag kan bli eliminert. Systemet vårt kan programmeres til å bli brukt som autopilot og det kan forhindre pilotfeil som stall og misstolkning av høyde. I 2010 ble det gjort en undersøkelse i USA, hvor det ble klart at mer enn 50% av alle amatørflyulykker skjedde grunnet pilotfeil.

Stikkord:
- Brukervennlig
- Fly-sikkerhet
- Elektronisk

Tilgjengelig: JA

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Dato: 14. Juni 2012

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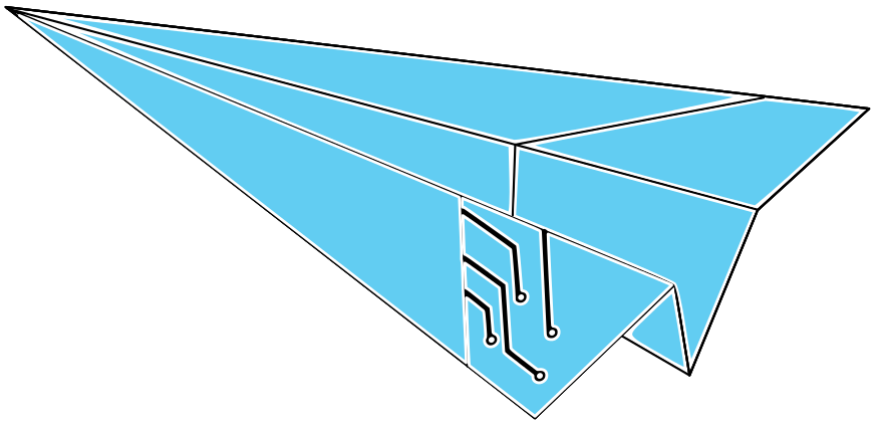
EQUATOR AIRCRAFT

Compact Fly-By-Wire System



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Made by	Ole Anders Riiser Kjetil Mjøs Axel Gravningsbråten Runar Løken Sindre Andersen Thomas Andersen

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1. INTRODUCTION:

This assignment was given to us by Equator Aircraft Norway, to develop a new Fly-By-Wire system for their new P2 Excursion prototype.

Fly-By-Wire is a general name of an electronic control system for aircrafts; it is mostly used in commercial airplanes, fighter jets and other large airplanes. The benefits of using a Fly-By-Wire system; it is very versatile when it comes to pilot assistance options and easy implementation of new functions.

By a survey conducted in 2010 in the USA, it was concluded that more than 50% of all small plane accidents in the same year was a result of pilot miss-control or pilot judgment. This means that more than 50% of all small planes accidents could have been avoided by using a computer assisted steering system aka a Fly-By-Wire system. And it stresses the need for such a system today!

Our task was therefore to develop a system that is redundant, durable and it must be ready for implementation of safety functions.

Idéskriv

Oppgaven

Oppgaven vi har mottat fra Equator Aircraft Norway er å utvikle et Fly-by-Wire system for et to seters amfibiefly.
I dag blir småfly styrt mekanisk av stag og vaiere fra styrestikke og pedaler. Dette gjør det vanskelig å implementere autopilot og overvåkningssystemer som kan hjelpe piloten.
Fly by Wire er et elektrisk styresystem som har erstattet det mekaniske systemet i større fly. Det ble først utviklet for jagerfly på slutten 50-tallet som i utgangspunktet blir flydd i en ustabil tilstand. Disse flyene ville vært umulige å styre uten elektronisk hjelp fra en rekke sensorer som holder flyet stabilt. Dette er nå standard i nye kommersielle fly pga. økt sikkerhet og vektbesparelser.
Systemet er foreløpig ikke benyttet i små fly, men vil også her kunne gi tilsvarende fordeler.

Vi skal skrive oppgaven på engelsk. Av dokumentasjon er oppdragsgiver interessert i en teknisk sluttrapport. Resten av dokumentasjonen blir levert inn som separate filer til høgskolen.
Første del av oppgaven går ut på å undersøke og sette oss inn i hvilke systemer som finnes i dag, og hva slags krav som stilles til slike systemer. Deretter skal vi undersøke feilsannsynlighet og utføre en feil tre analyse.
Sluttproduktet er et ferdig kretskort samt valg av aktuator. Oppdragsgiver vil at vi skal bevise funskjonaliteten i en FAT. Og det hele vil bli demonstrert i en avsluttende presentasjon. Ekstern veileder ønsker i hovedsak å benytte seg av epost til kommunikasjon og dropbox til utveksling av filer.

Oppdragsgiver

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PROJECT PLAN

Bachelor Project

Compact Fly-by-wire System

Version	2
Category	Released
Issue Date	25.05.2012
Made by	A.G, O.R, K.M, R.L, S.A and T.A

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3. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser
IMC / IMU	Internal Measurement Card; is an electronic device that measures and reports on the aircraft's velocity, orientation and gravitational forces, using a combination of accelerometers and gyroscopes.
MTBF	Mean Time Between Failures
MCC	Main Controller Card
SC	Supervision Card

Table 1: Abbreviation list

4. REFERENCES

Reference Document	Description
[1]http://www.equatoraircraft.com/	Contractor, history

Table 2: Reference list

5. PURPOSE

The purpose of this document is to have a project plan to work after. The document also contains information regarding time deadlines, definitions and responsibilities. The main goal for this project is to give practical experience with working in a group to solve a real world engineering problem.

6. INTRODUCTION

Our group got a task from the company Equator Aircraft Norway. This company developing a new type of small airplane, which will bring this type of airplane to a new dimension. We are to develop and construct the fly by wire control circuit for the plane.
Today, the fly by wire technology is not much used in small planes. Close to all planes in this category are controlled mechanically by wires and rods. Equator Aircraft thinks small airplanes also could benefit from the fly by wire technology. The goal for this project is to test our circuit with an FAT (Factory Acceptance Test). We will define this as our goal because we have limited time, and the prototype of the airplane that the circuit is going to be implemented in is not yet finished. This makes it impossible to test it with an SAT (Site Acceptance Test).

7. PROJECT MODEL

In our project we had to choose a development process. We have chosen to use the Rational Unified Process (PUP) because we think this model will help us to develop a good result in the end. The RUP model is based on the spiral model, which is a model that uses the same loop of research and control for every step we take, these loops are called iterations. One cycle in the process is approximately equal to the waterfall model. The RUP model is an iterative model which focuses on the risk early in the process. It is important to have an overview over the different risks that can affect the project. By focusing on the risks that can occur we are able to make some precautions which can help us prevent these risks, or if they still happen, we have a plan how to solve the problem. Because we do the same process a lot of times, this will help us to learn in the development process and the process will be improved for every cycle.
The RUP model is initially a software model, and since we do not have a pure software project we have to modify the model a bit to fit our project.

In our project the loops will be a bit different from the loops in a pure software project. We will have several iterations on every activity as they go along, which means that we will have some cycles going parallel in time. This will help us to find mistakes and improve the subsystem before we put all the different subsystems together and start the iterations on the entire system in the test phase.

The RUP model is based on a lot of elements that shows how the product should be and what skills that are needed to satisfy the requirements. The three main elements are: roles, tasks and work products. The roles define different skills and competencies. It also defines what responsibility the different roles have. The tasks are awarded to the different roles. A task is a unit of work that should be so good that it can be implemented in the final product. This result is a part of the element called work product, but it is not only this result. It is also all of models that are developed in the task and all documentation that has been written.

Every task in iteration can be divided into 9 disciplines. These disciplines are again divided into 6 “engineer disciplines” and 3 “supporting disciplines.” In our project it is the 6 "engineer disciplines” that are most important, and we will focusing most on these disciplines. The “supporting” discipline Project management is also important; this will be the one of the 3 “supporting” disciplines that we will spend most time with.

The whole project is, according to the RUP model, divided into 4 different phases. These phases are described according to where in the project process we are. The end of each phase should be marked with a millstone. To go further in the process some defined goals should be checked if they are satisfied according to the requirement specification.

The phases are divided into sub-phases, where the end of every sub-phase marks a small milestone. The secondary objectives contain a group of activities; one activity can last for maximum 14 days. One activity consists of several small iterations, where we work our way to a prototype, we check the prototype for faults and starts to improve it until it we are satisfied with the product. One Iteration might last from 1 day up to 10 days.

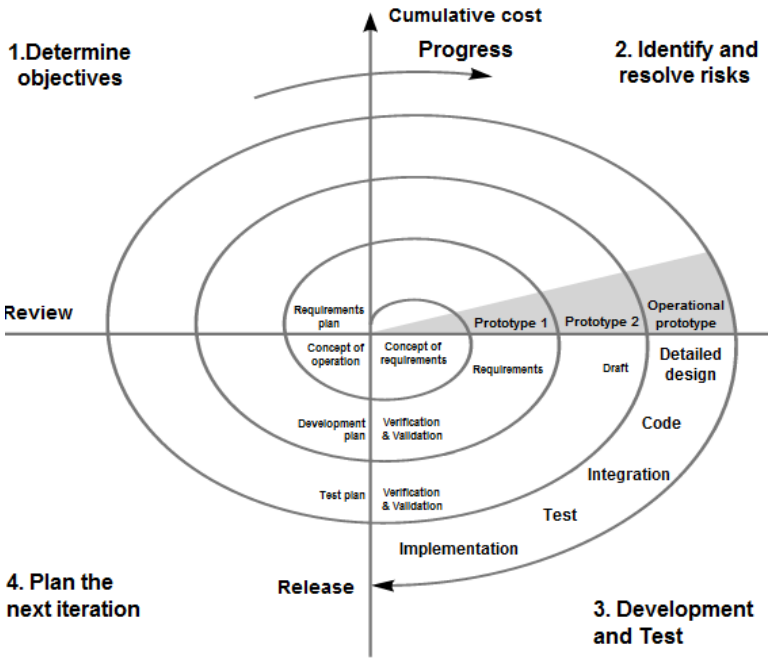

Figure 1: The spiral model

7.1. The four phases:

Inception - In this phase we should find the requirements and the limits of the project, it is also required that we discuss risks and costs. Design and usability should also be planed.

Elaboration - Here we should plan architecture and system requirements. It is also expected to find risks and approach to the problem before we go further in the process. In this phase it is time for producing a prototype, work further with the design and demonstrates the product for the contractor.

Construction - This phase includes developing of the program and the circuit. We should develop this product as fast as possible so the contractors can test the product and give feedback.

Transition - Means that we should test the prototype to find faults which we should repair before developing the complete product.

7.1.1. The nine different disciplines:

Engineer disciplines:

Business modeling - This discipline will help to make a better understanding between product developers and business developers. We should understand the structure and dynamic of the company that will use the product, and find problems and possible improvements.

Requirements - This includes finding what the system should be able to do, and which requirements that satisfies it.

Analysis and Design - This shows how the system will be realized in the implementation discipline.

Implementation - This includes developing parts to the system and putting them together including the software.

Test - This discipline include testing that all the needs of the system is implemented correct, and identifying mistakes in the system and correct them before further development.

Deployment - Here we present the product to the contractor and discuss the solutions.

Supporting disciplines:

Configuration and Change Management- In this discipline we are going to work with configuration management and status and goal management.

Project Management - Here it is required to work with risk treatment, project planning and control of the process development.

Environment - It is required to describe the processes that are necessary for the development process and improve project specific funds. We should also make an equipment list for the project.

When we look at the different phases and disciplines we can clearly see that all the disciplines extend over close to all the different phases. This property makes the model resistant to errors, and if it is necessary to change some specifications or requirements, this model is very modular.

8. PROJECT PLAN

8.1. Conditions

It is several conditions that have to be met in order to finish the project; the parts we need have to be ordered in time so we have time to implement and test them on the system. Therefore one of the important tasks is to find the right actuators and components, draw a circuit board and order the parts as early as possible. However in case something unexpected is to happen we will need to have an emergency plan ready. Another important factor is that the group have to put in a maximum performance as a whole and also individually. It is important for our group to have a precise timetable to follow. We have to make good plans ahead and try not to make the tasks too big and difficult, so they can be more foreseeable and easier to meet the deadlines.

8.2. Project objectives

The goals for this project is do implement a fly-by-wire system in the equator p2 excursion aircraft. The main functions of the system will be to control the flight control surfaces with a joystick without using mechanical transferring. We are replacing the pedals with the yaw axis on the joystick, and finding actuators for the control surfaces and the nose wheel. The final result will be made for easy configuration and implementation of external control inputs, such as autopilot and trim optimizer. In order to be sure we start and finish the most important parts first we divided the tasks into different priorities. We will start with priority 1 and continue to priority 7.

8.2.1. Priority 1

The first priority is to make and finish the circuit board design and send it in for production. This way we can start working with other problems until the circuit board returns from the supplier.

8.2.2. Priority 2

We need to find the best suitable Actuators / stepper motors at an early stage, so we can order them in early and be sure to have them before the last presentation, in case the delivery time is long.

8.2.3. Priority 3

The airplane is not set up with pedals, so the most important thing is to get the yaw axis of the joystick to turn the rudder without using mechanical transferring.

8.2.4. Priority 5

It is desirable with an easily configurable system with possibilities for external control inputs such as autopilot, trim optimizer, angle of attack limiter etc. It should also be possible to read the desirable values and the actual positions of the control surfaces on a display.

8.2.5. Priority 6

The P2 excursion is an amphibious aircraft, hence it can do the first test flights on water, and it is therefore not that important to implement the actuator for the nose wheel, though it is desirable.

8.2.6. Priority 7

Make a user friendly interface and make it compatible with Android

9. BUDGET

Organizing Budget

Activity	Estimated Cost
Presentations	400
Documentation	400

9.1.1. Presentations

This represents the costs associated with the presentations. This can be things we have to buy to make a better presentation and coffee to the audience.

9.1.2. Documentation

This is expenses like Printing of documents, binders, separators and such.

9.2. Materials Budget

The materials budget will contain all expected expenses incurred in this period which deals with the construction of the different solutions through the whole period. This is only an estimate and may vary with the solutions we come up with. We divide the materials budget into different groups indicating the period costs incurred.

Activity	Estimated Cost
Research	2000
Construction	
-Stepper motors	5000
-Production PCB	2500
-Other Components	1500
Sum	11000
Testing	1500
Total	12500

9.2.1. Research

We have to see which of the solutions we come up with which is the best to solve our problem. To do this, we need to construct and try different circuits and use different types of components to decide. If the school holds any of the components we need, we will borrow them.

9.2.2. Construction

When we have decided which of the solutions that is the best, we have chosen the components that we need. Therefore, we have to order the decided parts and get them soldered. The costs of this spot also contain printing on a PCB and different cosmetically components.

9.2.3. Testing

When we are finished constructing our product, we will test if it actually works like it's supposed to. If it doesn't we maybe have to buy other components. This point will apply together with 5.2.2 Construction.

10. TIME SCHEDULE

10.1. Phase 1: Inception

September 5th – January 12th.
In this phase of the project we have just started up, and at the beginning we don't even know which project we are doing yet. This had to be done as fast as possible. In the meantime we could figure out a lot of ground rules for the project, and there are a lot of things that has to be done before we can start the problem solving part of the task. In addition to finding a task we have to set up a lot of document templates that will save us a lot of time later on in the project. As soon as we got the project there was a set of documents we needed to deliver: Idea Document, Requirements Specification, Test Specifications and the Project plan. This is to be prepared for the next phase so we can start this as efficient as possible. The first phase ends up as the first presentation where we have to know exactly what we are making and when the different parts can be made.

Important Tasks
Find a Proper Project
Get the idea behind it and deliver the "Idea Document"
Make Templates
Deliver Project Plan, Requirement- and Test specification
Do the first presentation

Table 3: List of important tasks in phase 1.

Description	Start date	End Date	Estimated hour Count in this phase
Setting up document standards, project planning and initial research.	15.08.2011	25.09.2011	60
Meetings	15.08.2011	01.01.2012	60
Setting up budget	01.12.2011	01.01.2012	2
Making a Webpage	15.08.2011	01.01.2012	30
The First Presentation	01.01.2012	10.01.2012	20
Making the Idea Document	01.09.2011	01.10.2011	40
Writing the Technical Requirements	01.10.2011	05.01.2012	60
Writing the Test Specification	01.10.2011	05.01.2012	30
Writing the Project Plan	01.10.2011	05.01.2012	50

Table 4: List of activities phase 1

10.2. Phase 2: Elaboration

January 12th. – April 11th.
This is the phase where we design and develop the system. In the end of this phase we have to be sure that priority 1 to 3 is solved and that they are ready to be implemented. It is crucial that everybody in the group has defined tasks at all times. From this phase and through the rest of the project the group have to deliver a “Status Document” each week. This document contains: An overview from the tasks every person worked on last week, a plan over the tasks each person is going to work on next week, a general summary of how the progress is according to the project plan, make a summary of critical activities, append timesheet from last week. This phase ends up in the second presentation that has a technical perspective. By this presentation, most of the technical problems should be solved so we can discuss the solution with the supervisors and still have time to correct critical errors.

Important Tasks
Set up a basic test rig
Define all components needed
Order the components
Write the basis code for the system
Make layouts for the PCB boards
Do some functionality testing
Develop a Redundant System
Order PCBs

Table 5: List of important tasks phase 2

Description	Start date	End Date	Estimated hour Count in this phase
Technical Meetings with supervisors and planning	10.01.2012	29.03.2012	15
Starting on the accounting	10.01.2012	29.03.2012	4
Updating the webpage	10.01.2012	29.03.2012	15
Second presentation	20.02.2012	29.03.2012	40
Setting up a risk analysis	10.01.2012	29.03.2012	4
Write the Technical Document	20.01.2012	29.03.2012	60
Writing the weekly Status Report	10.01.2012	29.03.2012	70
Writing Fail probability document	20.01.2012	29.03.2012	35
Writing the Final Document	01.02.2012	29.03.2012	70
Software Development	10.01.2012	29.03.2012	640
Hardware development	10.01.2012	29.03.2012	800
Testing	10.01.2012	29.03.2012	150

Table 6: List of activities phase 2

10.3. Phase 3: Construction

April 11th. – May 29th.
This phase starts immediately after the second presentation. This is the last phase and is where we test everything together. After this stage all

Important Tasks
Do all the testing defined in the test specification
Finish all the technical documents
Do the main software development
Writing technical documents

Table 7: List of important tasks phase 3

Description	Start date	End Date	Estimated hour count in this phase
Technical Meetings with supervisors and planning	29.03.2012	01.06.2012	15
Accounting	29.03.2012	01.06.2012	10
Updating the webpage	29.03.2012	01.06.2012	25
Write the Technical Document	29.03.2012	01.06.2012	150
Writing the weekly Status Report	29.03.2012	01.06.2012	70
Writing Fail probability document	29.03.2012	01.06.2012	35
Writing the Final Document	29.03.2012	01.06.2012	200
Software Development	29.03.2012	01.06.2012	700
Testing	29.03.2012	01.06.2012	200
Implementation	01.04.2012	01.06.2012	300

Table 8: List of activities phase 3

10.4. Phase 4: Transition

May 29st. – June 8th.
Here we finish off the project and hopefully polish everything we have done.

Important Tasks
Finishing the Final report
Making Project Poster
Prepare a great final presentation

Description	Start date	End Date	Estimated hour Count
Accounting	29.03.2012	15.06.2012	10
Updating the webpage	29.03.2012	15.06.2012	25
Final Presentation	01.06.2012	11.06.2012	50
Write the Technical Document	29.03.2012	29.05.2012	150
Writing the weekly Status Report	29.03.2012	29.05.2012	70
Writing the Final Document	29.03.2012	29.05.2012	400
Software Development	29.03.2012	29.05.2012	50
Testing	29.03.2012	29.05.2012	40
Implementation	29.03.2012	29.05.2012	20

11. TIMELINE

11.1. Milestones:

Our milestones are important dates for our projects. These milestone dates are dates when our project is done with important tasks and phases.

1. 1st presentation; 10th of January 2012
2. Sending circuit board for printing 16th April
3. Primary software functions 15th March
4. 2nd presentation April – 23rd Mars 2012
5. First System function test 2nd May
6. The system shall be finished 18th May
7. 3rd presentation 2nd June – 12th June 2012

12. PROJECT ORGANIZATION

12.1. The Group

Name	Age	Course	Contact Info
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Thomas Andersen	23	Embedded Systems	Thomasandersen01@gmail.com Tlf:461 31 909
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Ole Anders Riiser	21	Cybernetics	riiserhob@gmail.com Tlf:480 24 862

Table 9: List of group members

12.2. Supervisors

Name	Age
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Olaf Hallan Graven	Olaf.hallan.graven@hibu.no

Table 10: List of supervisors

12.3. Group policy

There are a set of rules the members of the group should follow in order to operate smoothly together:

- Everyone will meet up at the appointed time, by omission – notify in good time
- Factual communication and acceptance
- All documents is collected in the “Equator_HiBu_2012” dropbox folder
- Democracy is used to meet agreement
- The roles as chairman and secretary will be changed at each meeting.
- Everyone will be given tasks, and they are expected to do the best they can to solve them.

12.4. About the contractor

Equator Aircraft Norway SA was established in 2011 [1]. The idea was born when industrial designer Tomas Brødreskift met Guenter Poeschel in 2008.

Guenter Poeschel is a mechanical engineer, GA test pilot and aircraft constructor. He started working on his aviation visions over 40 years ago. He founded Equator Aircraft Company GmbH in Ulm, Germany in 1974. Poeschel was way ahead of aircraft designers around the world and his old designs still represent some of the most innovative thoughts in the industry even today.
Tomas later teamed up with mechanic, industrial designer and professional pilot Øyvind Berven, and continued developing the P2 (now “P2 Excursion”). With this, Equator Aircraft Norway SA was established early 2011.

Today, Equator Aircraft Norway is a consortium of idealists from all over the world. They believe in an “open and idealistic approach where each member can apply a small amount of resources and see their dreams come alive”. They offer different levels of membership and involvement which you can read about on their webpage.

The EQP2 Excursion is a Carbon Composite Construction, Hybrid / Electric Powered Amphibian Aircraft. Aiming for the Experimental category first – followed by the ultra light, ELA & LSA markets.

12.5. Project Documentation

Document Name	Time of delivery	Responsible
Idea Document	Oct 1. 2011	Ole A. Riiser
Project Plan	Jan 8. 2012	KjetilMjøs
Requirements Specification	Jan 8. 2012	Axel Gravningsbråten
Technical Document	Jan 8. 2012	RunarLøken
Time Sheet	May 29. 2012	Kjetil Mjøs / Sindre Andersen
Requirement & test specification	May 29. 2012	Axel Gravningsbråten
Meeting Minutes	May 29. 2012	Sindre Andersen
User Manual	May 29. 2012	Axel Gravningsbråten
Product	May 29. 2012	Ole A. Riiser
SW Specification	May 29. 2012	Thomas Andersen

Table 11: List over project documentation

13. DESCRIPTION OF RESPONSIBILITIES

This is the official area of responsibilities:

Name	Responsibility
Ole Anders Riiser	Project manager, Testing
Sindre Andersen	Analysis and accounting
Thomas Andersen	Software and Web
Runar Løken	Document and Project Model
Kjetil Mjøs	Hardware
Axel Gravningsbråten	Requirements and Design

Table 12: Description of responsible persons

However, after working with the project for a while the area of responsibility has changes due to practical reasons, here is the actual list of responsibilities:

Name	Responsibility
Ole Anders Riiser	Project manager, Hardware, Circuit design
Sindre Andersen	Risk, Design and Accounting
Thomas Andersen	Software and Web
Runar Løken	Project Model & Simulation
Kjetil Mjøs	Redundancy & Testing, Actuator
Axel Gravningsbråten	Analysis, Document & Requirements

Table 13: Actual list of responsibilities

Table 14: shows the responsibility area for each person in the project group. There is only one person who has the main responsible for one area. But we have also set up a second person as a backup if someone get sick or is absent.

13.1. Project manager

The project manager has the main responsibility for the project. He has to that the time schedule is followed and deadlines are met. The project manager is also the person responsible for good communication with HIBU and equator aircrafts.

13.2. Economy and budgeting

The persons(s) responsible for the economy must have full control of the group budget and have to give consent if something needs to be purchased. He has to have a perfect understanding of the economical agreement between the group and the client. The economy responsible will pay back all the cash outlays as quick as possible.

13.3. Requirements

The person responsible for the requirements document. He will also have to follow up the requirements as they are met, and he will make sure that all the demands are taken into consideration.

13.4. Test

The test responsible is responsible for all the testing within the project, and all the test specifications and reports.

13.5. Web

The web responsible is responsible for the project web page, and will continuously make sure the web page is updated with the right information and pictures.He also has to check that sensitive material not get posted online. The address to our webpage is http://www.fbw.eu.pn/

13.6. Software

The software responsible has the overall response for the software code written in the project. He has to make sure the code has a good structure which is easy to read, efficient and modular made.

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13.7. Risk

The risk responsible is responsible for the risk analysis; this document will describe the probability and consequence for a given scenario. The responsible person will make sure the risk analysis is updated every time a new risk scenario occurs. He is also responsible for making an error-tree analysis.

13.8. Redundancy

The person(s) responsible for the redundancy must have a full overview of the system and its critical links, and is responsible for giving crucial information on redundancy to others in the group that are working on different aspects of the system. The person(s) responsible are also the key designers of the redundancy of the total system.

13.9. Circuit design

The circuit design responsible has the main response for the layout and design of the circuit board.

13.10. Documentation

The person(s) responsible for the documentation is expected to have full overview of all the documents in the Dropbox folder, as well as arrange the documents in an orderly manner. The document responsible will check that all the documents follow the project group's document standards and that everyone has signed the documents before they are delivered 48 hours (2 work days) prior to the presentations. Prior to the presentations the document responsible will also burn all the documentation on a CD, and he is responsible for not publishing sensitive information according to the contract with the client.

13.11. Actuator

Responsible for finding a suitable motor/actuator for controlling the ailerons, elevator, rudder and nose wheel.

14. REVISIONS

Responsible person for this document, procedure or template

rev	Description	Date	Name
01	First Draft; Milestones and Group policy	01.11.2011	A.G
02	Description of responsibilities	22.11.2011	A.G
03	Goals for the project and priority 1 -5	23.11.2011	A.G
04	Description of responsibilities, Tasks, Conditions, The group and Project documentation.	25.11.2011	A.G
05	Added Group information and delivery details, added time schedule, updated responsible areas, added activities	16.12.2011	O.R
06	Small grammatical changes to some of the text	19.12.2011	A.G
07	Filled in IMU definition. Edited and made new priority 1, updated 5.1, 6.11 and heading 1.1, 1.2 and 1.3	20.12.2011	A.G
08	Made new priority 2.	21.12.2011	A.G
09	Made budget, history of the contractor and phases of the project. Added new milestone, introduction and purpose. Updated table captions and added table list. Updated project objectives. Removed priority 4. Updated phase dates and text. Updated responsible person list and dates of document hand in. Cosmetic changes to tables	03.01.2011	K.M, S.A, O.R & A.G
0.10	Revised responsibilities Made table of figures and Project model RUP	04.01.2012	A.G, R.L
1.0	First Release	6.1.2012	O.R
1.1	Updating web information Updating project model Updated phases	11.01.2012	R.L
1.2	Updating project model	13.01.2012	R.L
1.3	Updating Activity numbers	16.1.2012	O.R
1.4	Updated and edited: 8. Project model	23.02.2012	A.G
1.5	Updated activities	07.03.2012	S.A
1.6	Updated 13 DESCRIPTION OF Responsibilities	11.05.2012	A.G
2.0	Made final revision, did some small changes	23.05.2012	A.G

Table 14: List of document revisions

Risk Analysis

Group 3

Compact Fly-by-wire system

Version	1.0
Category	Released
Issue Date	26.05.2012
Made by	S.A, R.L
Checked by	A.G
Approved by	S.A

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2. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser

Table 1: Abbreviation

3. INTRODUCTION

3.1. The purpose of this document.

The risk analysis contains risk evaluation of different groups of risk. The risks evaluated in this document will assist the other documents and may be referred to later. By evaluating the risks in advance, will help us to avoid problems before they occur. If the problems occur, we will have the solution and already know how to solve them. The risk analysis will contain a description of the problem, information about the probability for the problem to happen, how to prevent the problem, the consequence and how to solve the problem.

4. SCALE

Scale	Color
1 – 2 (Very unlikely)	
3 – 4 (Unlikely)	
5 – 6 (Possible)	
7 – 8 (Likely)	
9 – 10 (Very likely)	

Table 2: Scale

5. TEMPLATE

Risk #	Name	Probability:	Consequence:
Description			
Probability			
Prevention			
Consequence			
Solution			
Owner & date			

Table 3: Template

6. RISKS

6.1. Requirement risks

Risk 1	Not satisfied A req.	Probability: 2	Consequence: 10
Description	The group has not met the “A” requirements		
Probability	Unlikely		
Prevention	We have to work properly with our tasks, comply with deadlines and choose the most effective solutions		
Consequence	Our product will not meet the requirements of our contractor, and we will end up with a product with lack of basic functionality.		
Owner & date	S.A 11.01.2012		

Table 4: Risk 1

Risk 2	Not satisfied B req.	Probability: 5	Consequence: 7
Description	The group has not met the “B” requirements		
Probability	Possible		
Prevention	We have to work properly with our tasks, comply with deadlines and choose the most effective solutions		
Consequence	Our product will not meet all the requirements of our contractor, and we will end up with a product with lack of functionality.		
Owner & date	S.A 11.01.2012		

Table 5: Risk 2

Risk 3	Not satisfied C req.	Probability: 8	Consequence: 3
Description	The group has not met the “C” requirements		
Probability	Likely		
Prevention	We have to work properly with our tasks, comply with deadlines and choose the most effective solutions		
Consequence	Our product will not meet all of the requirements of our contractor, and we will end up with a product with lack of the extra ordinary functionality.		
Owner & date	S.A 11.01.2012		

Table 6: Risk 3

6.2. Development risks

Risk 4	Lack of technical knowledge	Probability: 5	Consequence: 8
Description	We will later on in the development of this project meet a point where we have a lack of technical knowledge.		
Probability	Possible		
Prevention	We must acquire technical knowledge through the whole period		
Consequence	We will not be able to deliver a complete product		
Solution	We must acquire technical knowledge through the whole period		
Owner & date	S.A, R.L 12.01.2012		

Table 7: Risk 4

Risk 5	Lack of components	Probability: 5	Consequence: 5
Description	The probability that we get a lack of components and late deliveries		
Probability	Possible		
Prevention	Order the components in good time, and do thorough research in good time prior to each phase and sub-phase		
Consequence	The construction may be delayed.		
Solution	We will change our plan, try to do other tasks that can be solved so we will not lose time		
Owner & date	S.A, R.L 12.01.2012		

Table 8: Risk 5

Risk 6	Wrong delivery	Probability: 2	Consequence: 9
Description	The probability that we get the wrong parts or do not get the ordered parts at all		
Probability	Very unlikely		
Prevention	We cannot do much if we get the wrong parts. We have to trust the producers and distributers		
Consequence	There is a big probability that we will not be able to order new parts in time which leads to an unfinished product		
Solution	Order new parts on express mail, and hope the reorder will be delivered in time		
Owner & date	S.A, R.L 12.01.2012		

Table 9: Risk 6

Risk 7	Disagreement about the technical solution	Probability: 7	Consequence: 2
Description	Some of the members have different opinions about the technical solutions		
Probability	Likely		
Prevention	This is a positive risk		
Consequence	Some of our members may feel run over by the others and we spend more time than if everyone agree with the solutions		
Solution	We have to discuss, analyze and agree with one solution.		
Owner & date	S.A, R.L 12.01.2012		

Table 10: Risk 7

Risk 8	Probability for loss of data	Probability: 2	Consequence: 9
Description	The probability for loss of data if we get a computer-crash		
Probability	Very unlikely		
Prevention	We have data backup on dropbox and on every computer		
Consequence	Loss of data		
Solution	We have to rewrite the lost documents if we have time		
Owner & date	S.A, R.L 12.01.2012		

Table 11: Risk 8

Risk 9	Damaged hardware	Probability: 3	Consequence: 9
Description	The probability that we damage the hardware		
Probability	Unlikely		
Prevention	We have to be careful when we are working with the hardware and use ESD protection when handling the circuit boards		
Consequence	The hardware may be destroyed		
Solution	Order new hardware if time allows.		
Owner & date	S.A, R.L 12.01.2012		

Table 12: Risk 9

6.3. Working progress risks

Risk 10	Illness	Probability: 9	Consequence: 3
Description	Some of our members become ill during the project		
Probability	Very likely		
Prevention	Each one has to be careful not to be ill.		
Consequence	We will have one less working person for a couple of days		
Solution	There should be at least two persons working with each task so the progress will not stop because of one person.		
Owner & date	S.A, R.L 12.01.2012		

Table 13: Risk 10

Risk 11	Injury	Probability: 1	Consequence: 5
Description	Some of our members become injured during the project		
Probability	Unlikely		
Prevention	No one knows what tomorrow brings. So we have to be careful		
Consequence	We will have one less working person for a period		
Solution	There should be at least two persons working with each task so the progress will not stop because of one person.		
Owner & date	S.A, R.L 12.01.2012		

Table 14: Risk 11

Risk 12	Some quits school	Probability: 1	Consequence: 7
Description	Someone quits school because of personal or professional reasons		
Probability	Very unlikely		
Prevention	We have to motivate and respect each other and work with teambuilding		
Consequence	We will have one less working person for the rest of the project		
Solution	The other persons in the group have to divide the tasks to the missing person between the remaining members of the group.		
Owner & date	S.A, R.L 12.01.2012		

Table 15: Risk 12

Risk 13	Lack of motivation	Probability: 5	Consequence: 3
Description	Someone in the group get lack of motivation during the project which leads to bad working spirit.		
Probability	Possible		
Prevention	Allow each other to decide working hours, keep building team spirit and get through boring tasks.		
Consequence	The working progress will slow down.		
Solution	Allow each other to decide working hours, keep building team spirit and help others through boring tasks.		
Owner & date	S.A, R.L 12.01.2012		

Table 16: Risk 13

Risk 14	Losing our supervisors	Probability: 2	Consequence: 8
Description	Losing our internal or/and external supervisors		
Probability	Very unlikely		
Prevention	Arranging meeting and make conscientious effort		
Consequence	We will get inadequate follow-up		
Solution	We have to find a new internal or/and external supervisor.		
Owner & date	S.A, R.L 12.01.2012		

Table 17: Risk 14

Risk 15	Time shortage	Probability: 9	Consequence: 4
Description	That we are using more time than expected		
Probability	Very likely		
Prevention	Work evenly hard during the whole project		
Consequence	We get less leisure and we may not finish all of the tasks		
Solution	Work more and make the right priorities		
Owner & date	S.A, R.L 12.01.2012		

Table 18: Risk 15

Risk 16	Too much time	Probability: 1	Consequence: 2
Description	That we are using less time than expected		
Probability	Very unlikely		
Prevention	Have a list of different tasks and improvements.		
Consequence	We get more leisure and finish all tasks		
Solution	We need to find tasks and improvements		
Owner & date	S.A, R.L 12.01.2012		

Table 19: Risk 16

7. REVISIONS

Responsible person for this document, procedure or template

rev	Description	Date	Name
01	Made templates, wrote introduction and made the requirement risks	11.01.2012	R.L & S.A
02	Made risks 1-16	12.01.2012	R.L & S.A
03	Fixing grammar	12.01.2012	A.G
04	Did some cosmetic changes to the tables	13.01.2012	A.G
1.0	Made the PDF copy and checked the document for errors	13.01.2012	A.G

Table 20: Revisions

ACCOUNTING DOCUMENT

Compact fly-by-wire system

Version	1.0
Category	Released
Issue Date	29.05.2012
Made by	S.A
Checked by	A.G
Approved by	O.R

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2. INTRODUCTION

This document contains a list of purchased items during the project.

3. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser

Table 1: Abbreviation

4. PRODUCT PURCHASE LIST

Product	Price(NOK)	Buyer	Status	Date
Tape	29	S.A	Paid	03.01.12
Coffee for the first presentation	135	K.M	Paid	10.01.12
Biscuits for the first presentation	29	S.A	Paid	10.01.12
Paper plates & plastic knives	37	A.G	Paid	12.01.12
Fuel for meeting 3 14 NOK/L	196	A.G	Paid	08.02.12
Spraypaint and sanding paper	149	S.A	Paid	18.03.12
Coffe and biscuits for the second pres.	175	S.A	Paid	18.04.12
Food for teambuilding and meeting with Knut	215	S.A	Paid	25.05.12

Table 2: Product purchase list

5. PARTS PURCHASE LIST

Product	Supplier	Price(NOK)	Buyer	Status	Date
IMU	www.sparkfun.com	1186 (order1)	S.A	Paid	09.02.12
GPS	www.sparkfun.com	Order1	S.A	Paid	09.02.12
One wire	www.sparkfun.com	47(order 2)	S.A	Paid	09.02.12
PSU	www.ebay.com		S.A		09.02.12
3.3V regulator	www.ebay.com	Order 2	S.A	Paid	09.02.12
Linear voltage regulator	www.ebay.com	Order 2	S.A	Paid	09.02.12
LEDS	www.ebay.com		S.A		09.02.12
Stepper controller	www.pololu.com	141	S.A	Paid	09.02.12
Microcontrollers	www.mikroe.com	592	S.A	Paid	24.02.12

Taxes	Order 1	237	S.A	Paid	24.02.12
Taxes	On microcontrollers	264	S.A	Paid	05.03.12
Sample connector	Elfa electronics	128	S.A	Paid	19.03.12
MCC PCB cards	pcbCart.com	1187	S.A	Paid	1.4.2012
Stepper controllers	Pololu.com	1100	S.A	Paid	3.4.2012
Parts from ebay	Ebay.com	203	S.A	Paid	3.4.2012
Cables, connector and a lot of small parts.	Ebay.com	1107	S.A	Paid	9.4.2012
Power connectors	Digikey.com	200	K.M	Paid	18.4.2012
Potmeters and misc	www.sparkfun.com	436	S.A	Paid	18.4.2012
Usb connector resistors and transistors, two stepper motors and other misc.	Ebay.com	490	O.R	Paid	
LPC1768 and debugger	Ebay.com	382	O.R	Paid	
Capacitors headers and potentiometer	Ebay.com	69	O.R	Paid	
10 Rocker switches, green leds, red leds and standoffs	Ebay.com	108	O.R	Paid	
Ordered SC PCB card	Pcbcart.com	1116	S.A	Paid	
Ordered ammeters	Ebay.com	63	O.R	Paid	27.04.2012
74HCT365	Ebay.com	69	O.R	Paid	02.05.2012
LM3526-L	Elfa	147	O.R	Paid	02.05.2012
Metal plate, epoxy and cutting disc	Biltema	70	S.A	Paid	02.05.2012
Spray paint	Maxbo Hokksund	107	S.A	Paid	07.05.2012
Metal plates, brackets	Biltema	73	S.A	Paid	14.05.2012
Shrink tube	Biltema	25	A.G	Unpaid	15.05.2012
Tape	Biltema	35	S.A	Paid	15.05.2012
Spraypaint, wood, sanding paper	Maxbo Hokksund	180	S.A	Paid --	17.04.2012
Ties	Biltema	46	A.G	Unpaid	19.05.2012

Table 3: Purchased items

6. RESULT

Post	Budget	Spent	Result
Research	2000	0	**2000**
Stepper Motors	5000	260	**4740**
PCB-Production	2500	2303	**197**
Other Components	1500	6745	**-5245**
Testing	1500	500	**1000**
SUM	12500	9808	**2692**

7. REVISIONS

Responsible person for this document, procedure or template

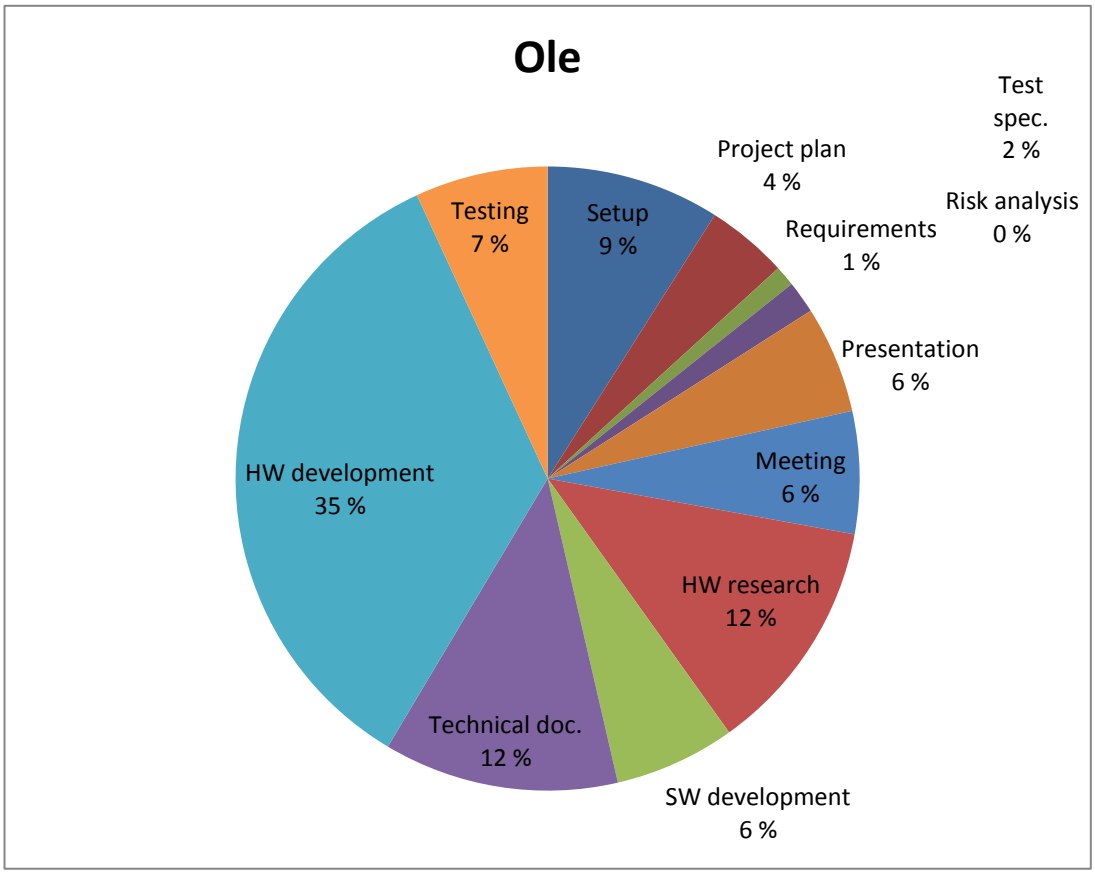
rev	Description	Date	Owner
0.1	Made table for accounting	12.01.2011	S.A
0.2	Updated Purchase lists,	09.02.2012	S.A
1.0	Checked for errors and approved, Added the result table for better overview	22.05.2012	S.A, O.R

Table 4: Revisions

COMPLETE TIME SHEET

Activity name	Activity number	Ole	Kjetil	Axel	Sindre	Runar	Thomas
Setup	1	51	25,5	12	19	13	3
Project plan	2	24	32,5	12,5	36,5	65,5	48
Requirements	3	6	12,5	45,5	0	0	0
Test spec.	4	9,5	0	16	0	13	12
Risk analysis	5	0	0	0	12	6	0
Presentation	6	31,5	36,5	36	26	33,5	27
Meeting	7	36	31	57	56	48	30,5
HW research	8	69,5	29	36	71,5	100	10,5
SW development	9	35,5	265	1	0	159,5	270
Technical doc.	10	69	46	232	160,5	34	24
HW development	11	196	0	33,5	100,5	8	0
Testing	13	39	89,5	7,5	8	29	53
Sum		567	567,5	489	490	509,5	478

Activity name	Activity number	Sum
Setup	1	123,5
Project plan	2	219
Requirements	3	64
Test spec.	4	50,5
Risk analysis	5	18
Presentation	6	190,5
Meeting	7	258,5
HW research	8	316,5
SW development	9	731
Technical doc.	10	565,5
HW development	11	338
Testing	13	226
Sum		3101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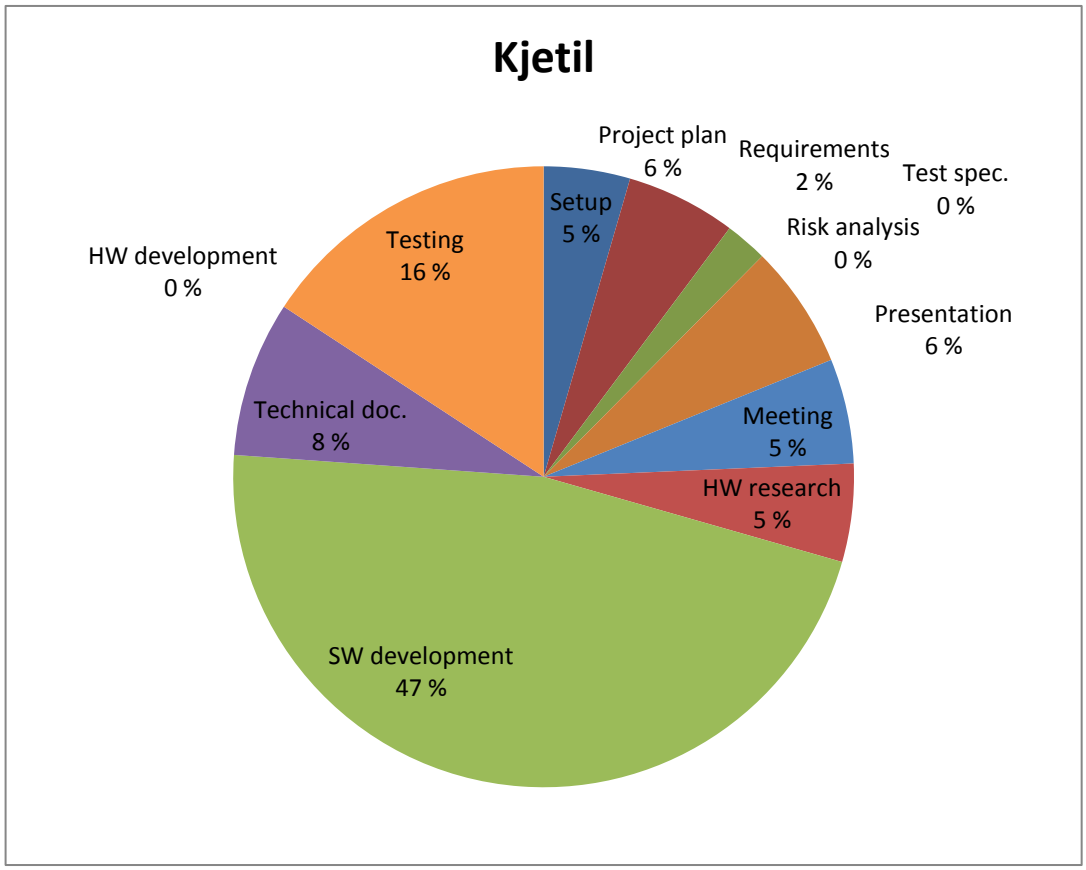
Project plan 4 %
Risk analysis 0 %
Requirements 1 %
Testing 7 %
Setup 9 %
Presentation 6 %
Meeting 6 %
HW development 35 %
HW research 12 %
Technical doc. 12 %
SW development 6 %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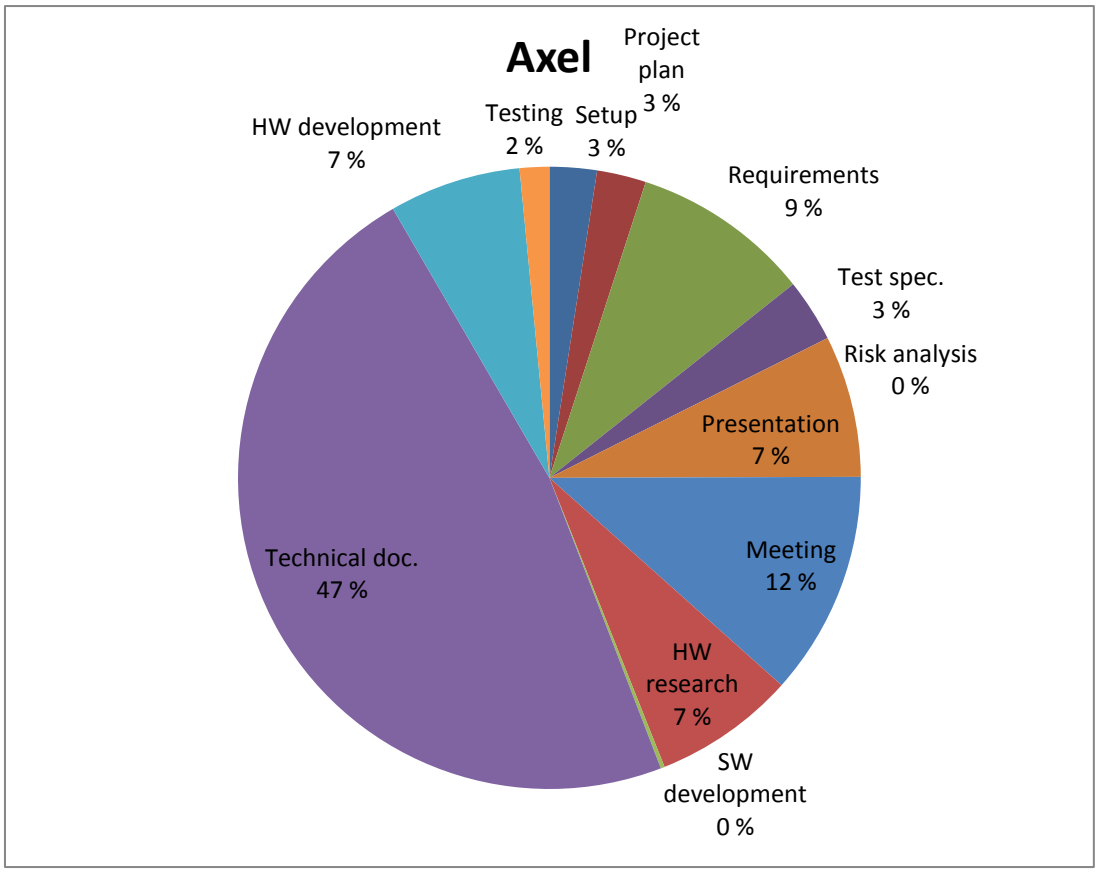
Requirements 2 %
Test spec. 0 %
Risk analysis 0 %
Setup 5 %
Testing 16 %
HW development 0 %
Presentation 6 %
Technical doc. 8 %
Meeting 5 %
HW research 5 %
SW development 47 %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Project plan 3 %
Testing 2 %
Setup 3 %
HW development 7 %
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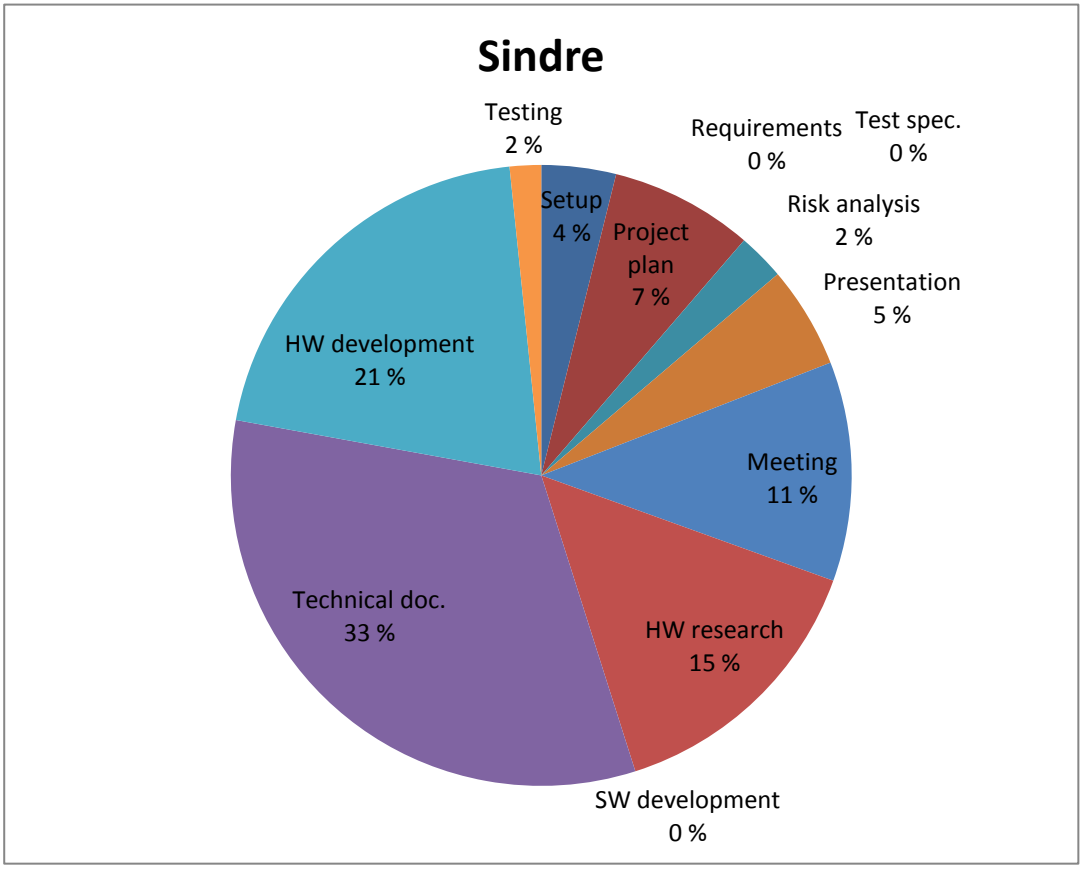
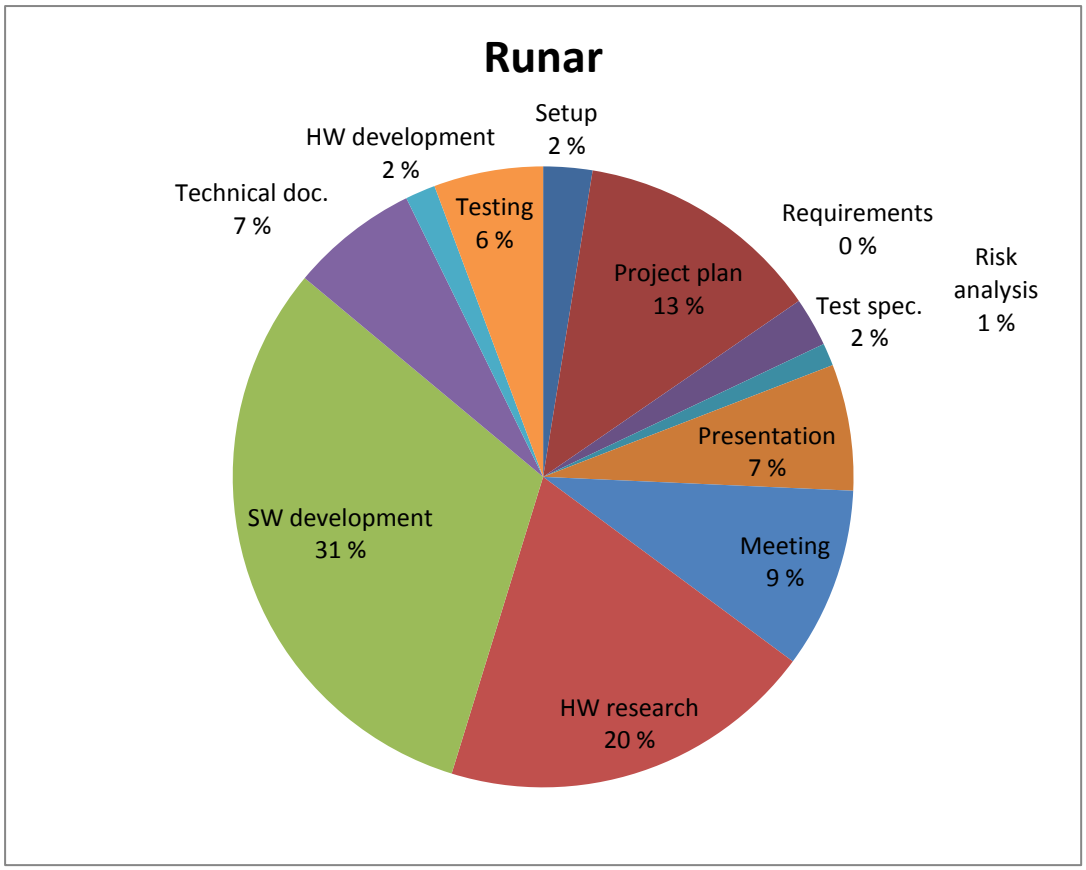
Test spec. 3 %
Risk analysis 0 %
Presentation 7 %
Meeting 12 %
HW research 7 %
SW development 0 %
Technical doc. 47 %


Sindre
Testing 2 %
Requirements 0 %
Test spec. 0 %
Setup 4 %
Project plan 7 %
Risk analysis 2 %
Presentation 5 %
HW development 21 %
Meeting 11 %
Technical doc. 33 %
HW research 15 %
SW development 0 %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Testing
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Requirements
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Test spec.
2 %
Presentation
7 %
SW development
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Meeting
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HW research
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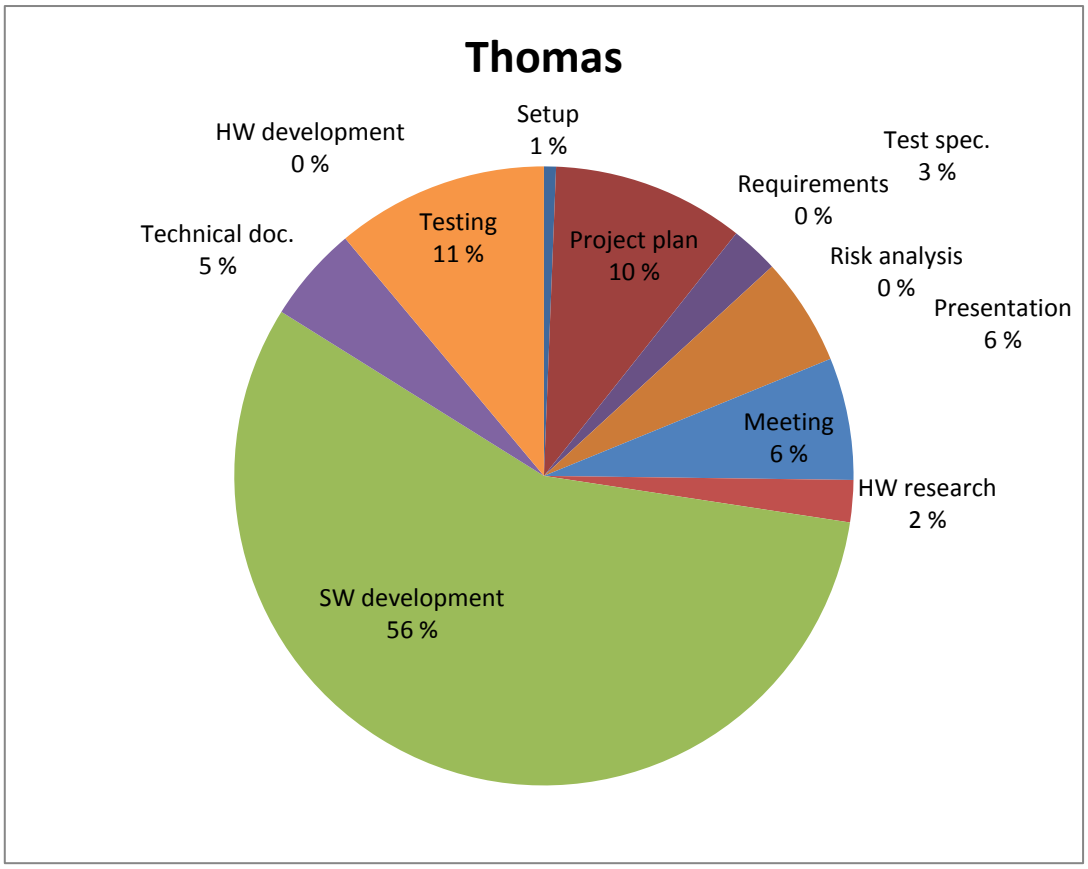
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Technical doc.
5 %
Testing
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Project plan
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Risk analysis
0 %
Presentation
6 %
Meeting
6 %
HW research
2 %
SW development
56 %

User Manual

Compact Fly-By-Wire System

Equator Aircraft

1. WELCOME

Congratulations on your new P-2 Excursion!
Before you go flying please read this document carefully to ensure a safe and pleasant flight.
We want you to spend as much time to enjoy flying and as little time as possible on concerning for you safety. This document will guide you step-by-step through the different control features of the Compact-Fly-By-Wire System.

This is a document directed only towards the user interface, and contains no technical documentation or data. For technical support please read the Technical User Manual.

2. SC

The SC is a supervisor Card that supervises the system and reports errors and alarms.
It also supervises the pilot inputs and can prevent critical pilot errors like stalling and altitude misjudgment during landing. If the SC is turned off (read: Analog HMI) the system will work normally without any safety features.

3. JOYSTICK

The joystick is the most important part of the system, as it is what transfers your inputs to the system and further out to the control surfaces.

Note: All the joystick axes sends out a linear control signal.

3.1.1.1. Pitch

By using the Pitch axis on the joystick (the forward and backward movement) you will control the elevator. Pushing the elevator forward will point the elevator down, and during flight the aircraft nose will point down and you will lose altitude. By pulling the stick towards you the elevator will point upwards, and during flight the aircraft will point upwards and you gain altitude.

When SC is activated a stall limiter will prevent the aircraft from stalling, by stopping the elevator movement upwards if the aircraft is close to stalling.

WARNING: When the SC is deactivated be aware of the stall speed when attempting to increase altitude, make sure you have sufficient speed before pulling the joystick.

3.1.1.2. Roll

The roll axis (sideways movement) on the joystick controls the ailerons. Pulling the joystick to the right will cause the aircraft to bank to the right, and vice versa.

When banking the aircraft the stall speed increases, when SC is activated it will prevent a stall from happening by limiting the bank angle and increasing the speed.

WARNING: When the SC is deactivated be aware that the stall speed increases when banking the aircraft.

3.1.1.3. Yaw

The Yaw axis (twisting movement) on the joystick controls the rudder, the nose wheel and the water rudder. By twisting the joystick to the right the aircraft's horizontal direction will start pointing to the right.

When the aircraft is located on water, a small water rudder will ensure maneuverability on the sea, by twisting the joystick to the right during forward movement, the aircraft will turn to the right.

When the landing gear is activated and the aircraft is located on a runway, the yaw axis controls the nose wheel. Twisting the yaw axis to the right will turn the nose wheel to the right and the aircraft will turn right.

3.1.2. Autopilot

The autopilot can be activated from the joystick, by using the AP button (ON/OFF Switch)
This autopilot setting is a simple autopilot without possibility of automatic take-off & landing and waypoints.

With the joystick autopilot option you can set desired altitude with the ALT button, and set the compass heading with the HDG button.

Figure1: Joystick with autopilot

4. ANDROID TABLET

On the next page is an example of the factory set user interface of the Android flight instrument panel.
The Tablet is the main instrument panel of the aircraft, and it handles all the information you need, we advise you to use some time to get to know the functions of it.

In the above example you can see the factory settings of the instrument panel, containing;

- Google map with airspace zones
- Compass heading
- Distance to destination
- Time to destination
- Altitude
- Airspeed
- Ground speed
- Autopilot settings
- System status

Warnings and alarms will automatically pop up on the screen no matter the user settings.

The autopilot is available with vast possibilities of functions, with waypoints, automatic takeoff and landing, automatic altitude settings according to the airspace zones. Etc.

You can set other information bars, change the sizes and add more, the user interface can be customized to suit your needs and wishes. There is also possible to download new functions from Android Market by registering your name and flight registration number. The Marked will be updated regularly with new functions and updates.

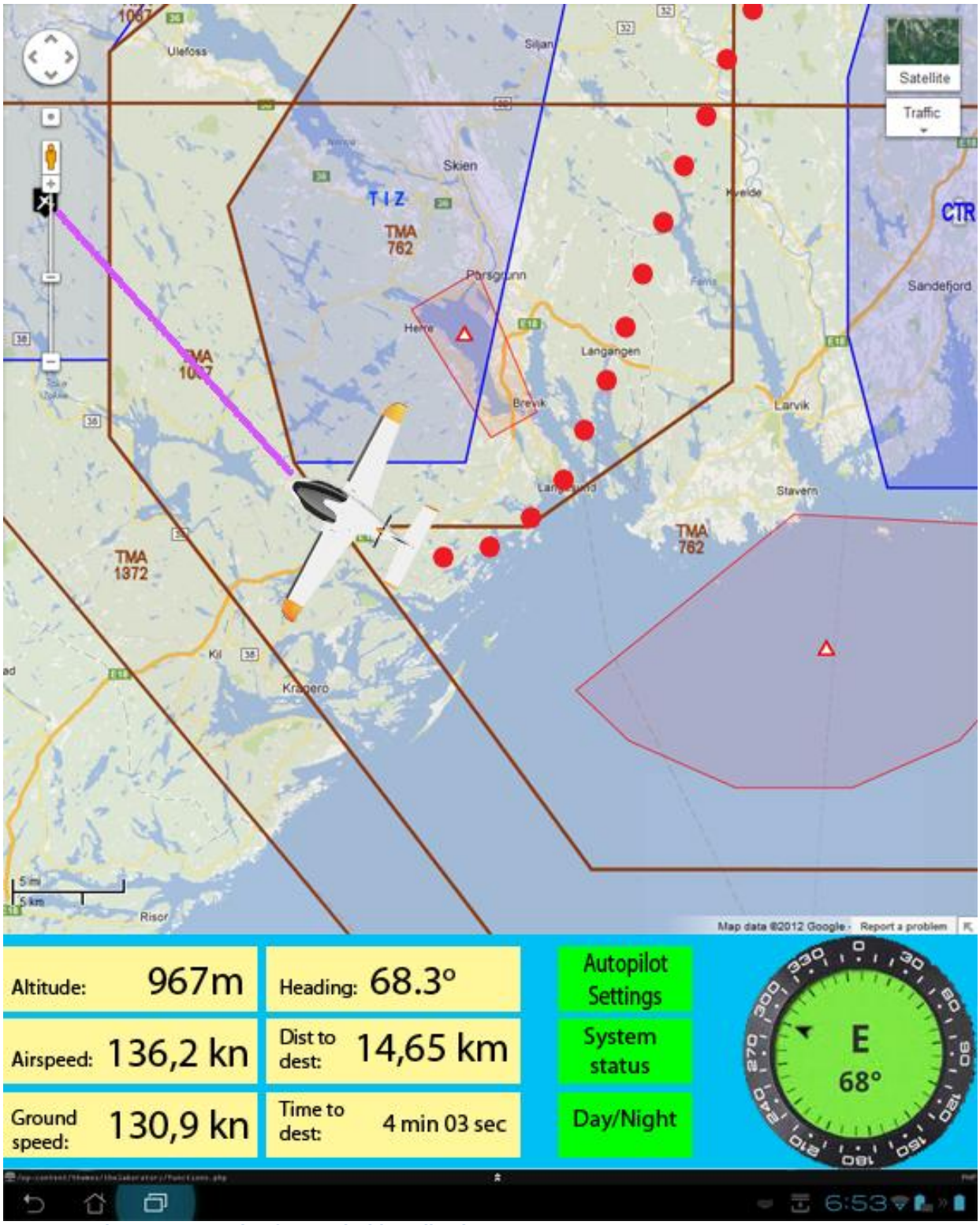

Figure 1: Example of an Android application

5. ANALOG HMI

WARNING: When activating the override button, only activate one at a time! Activating of multiple Main controller cards can damage the system, and cause failure!

If the SC fails to supervise the system or you do not want the safety features to interfere with your flying, you can override the choice of controller manually by pushing one of the three buttons on the Analog HMI board, you will then choose the respective MCC as operative. You can also see the status of each card on the LEDs.

To ensure that the system starts up correctly when powered, check if all the LEDs turn green before take-off! If any LEDs don't turn green, try to turn off the power for 5 seconds and repower the system. If the problem persists, contact a technician.

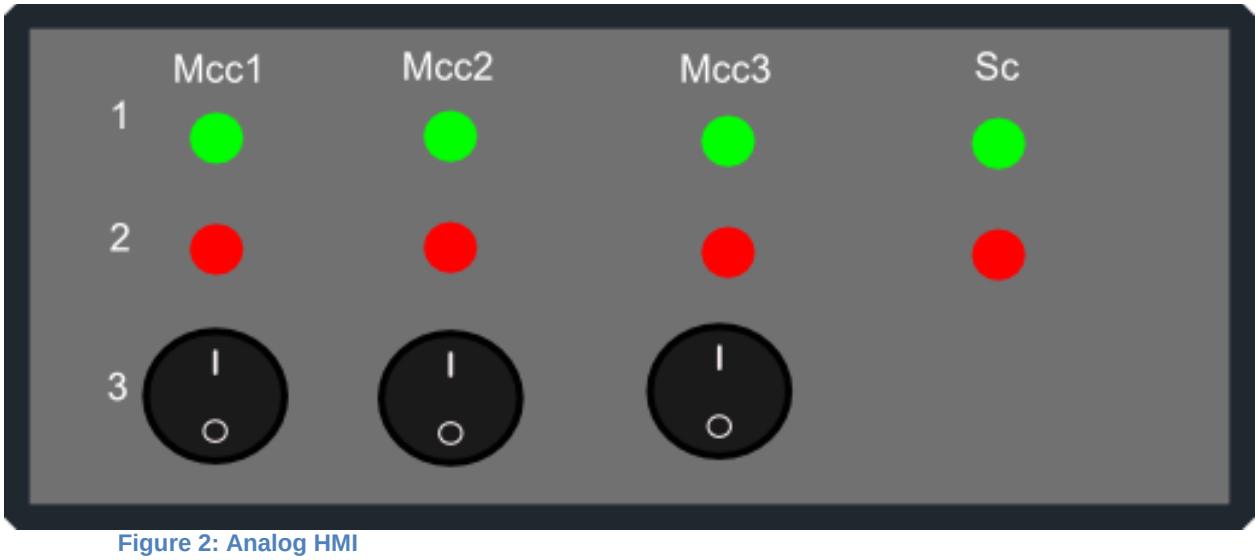

Figure 2: Analog HMI

6. FURTHER INFORMATION

For a more detailed explanation of the functions please read:

- SW description
- HW description

For information on how to assemble the system and troubleshooting please read:

- System topology
- MCC wiring diagram
- SC wiring diagram
- HMI wiring diagram

6.1.1.1. Contact

For further assistance please do not hesitate to contact Equator Aircraft Norway on:

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e-mail: mail@equatoraircraft.com

phone: (+47) 970 39 469

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0186 Oslo
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Norway

Technical Manual

Compact FBW System

Equator Aircraft

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2. PURPOSE

This document is intended for the technician of the Compact Fly-By-Wire System, and it explains how to assemble and wire the system. How to connect a computer and how to do Software changes on the system, and how the system works in general.

3. THE SYSTEM

3.1. Introduction

The system we make is a replacement for the old manual steering system for light airplanes. It is supposed to mimic the movements that the old system has but also prevent critical pilot errors like stall angle etc. The system can also be implemented with autopilot etc. for computer assisted flight.
The system (Figure 1) consists of three Main controller cards (MCC) which by itself can control the airplane, but since electronics are more likely to fail then wires we made the system triple redundant. They get joystick readings from a triple redundant joystick which has three axes and has their own stepper controller for actuation of the control surfaces. The stepper motors on the control surfaces has a really high life expectancy so they don't need redundancy.
The three MCCs needs supervision so they don't overrides each other and this is why we have the supervisor card (SC). The supervisor card receives information from all the MCCs and decides which one that is in command and controls the control surfaces. We have also a USB-host port on the supervisor so it can be interfaced with an android device for easy access to information and you can control various parts of the system with the autopilot. The SC also contains a lot of sensors for measuring the planes orientation, velocity and height which can be used as pilot assistance and reference for autopilot. The sensors we have included are:

Internal sensors:

- Accelerometer
- Gyroscope
- Magnetometer
- Barometer
- GPS

External sensors

- Ultrasonic range sensor
- Airspeed sensor
- Angle of attack sensor

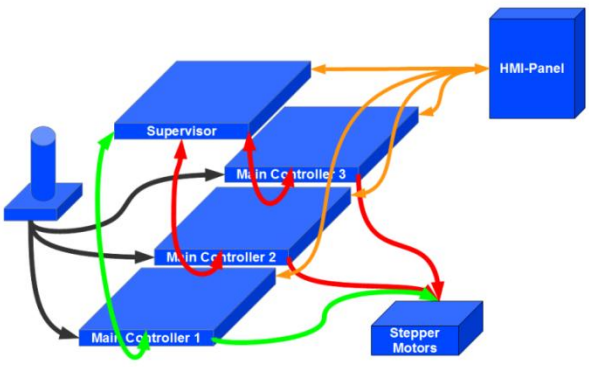

Figure 1: System diagram

3.2. The Main Controller Card

3.2.1. Introduction

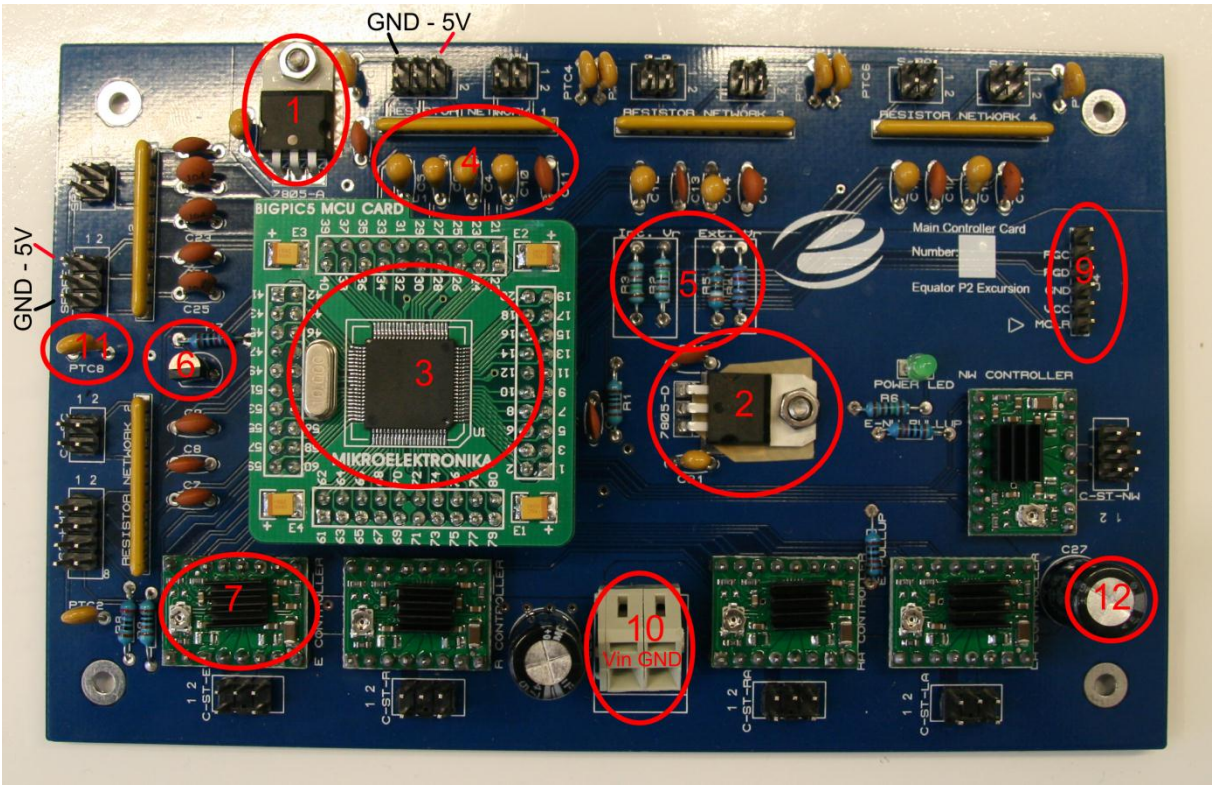

Figure 2: MCC Part Description

1. 7805 5V regulator for Analog Circuitry(Warning: The output voltage from this regulator needs to be lower than the voltage in **2,** we mounted regulators on **1** that was at least 50-100mV. Every 7805 has a slightly different output voltage)
2. 7805 5V regulator as a power supply, this regulator supplies 5v to everything except the analog circuitry.
3. PIC18F8520 breakout board from mikroelectronika
4. RC filter to protect every input, the resistor network is 5 isolated resistors.
5. Voltage read by voltage division
6. DS18B20 temperature sensor, one wire protocol.
7. Stepper Controller for one stepper motor.
8. NA
9. Programming connector for PICKIT2 programmer
10. Power Connector(7v-25V input)
11. PTC fuse, this blocks 5v to connector if current exceeds 0.25A
12. 470uF capacitor to remove transients.
    Another note that is important is the standardization of the connectors, 5v is always on Pin1 marked on the board and GND is on the second last pin as drawn on the board. This is the default on all connectors!

3.2.2. Software

The development of software for the main controller cards is done using MicroC Pro for PIC. A link to the download page for the software is found here: http://www.mikroe.com/eng/products/view/7/mikroc-pro-for-pic/ (22.05.2012). The free demo version has a program limit of 2kB. A dongle with a full licence is supplied with the compact fly by wire product. A user manual for the MicroC compiler is found here: http://www.mikroe.com/eng/downloads/get/30/mikroc_pic_pro_manual_v101.pdf (22.05.2012).

When a project is compiled a hex file is created. There is two ways of getting this hex file onto the PIC microcontroller.

One way is by using the BigPic5 development board. When pressing the compile and program with the BigPic5 connected the code will be uploaded to the controller. The controller chip can then be taken out and inserted into one of the three main controller cards.

The other way of getting the hex file onto the main controller cards is by using a PICKit programmer.

Figure 3: The PICkit2 programmer

We have been using the PICkit2 programmer but the PICkit3 should also work. Software for the PICkit can be downloaded from here: http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en023805 (22.05.2012).

The programmer connects to part 9 on Figure 2. The arrow on the card should point towards the arrow on the programmer. Start the PICkit2 programmer by pressing this icon:

The main screen is then showed:

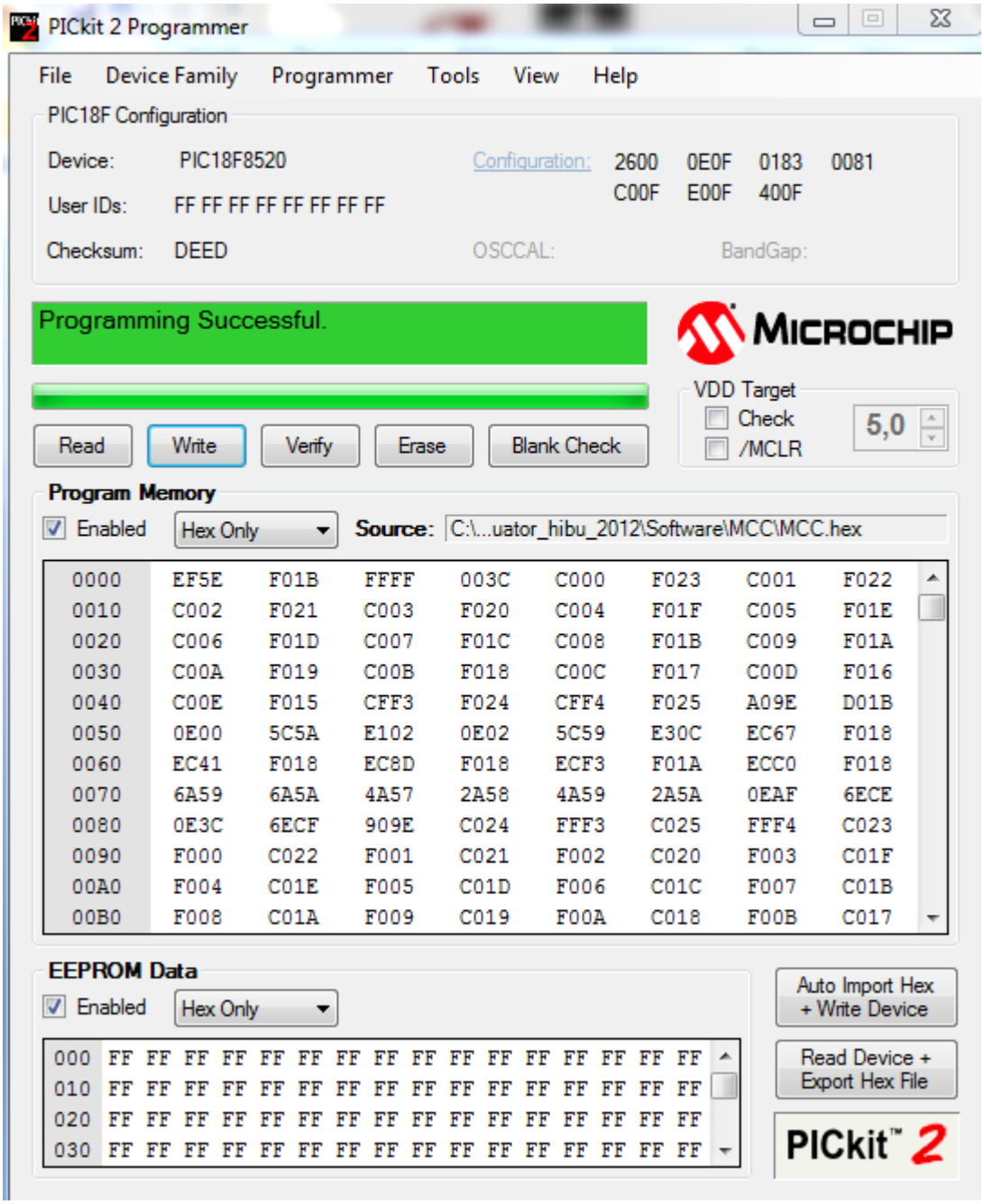
PICkit 2 Programmer
File
Device Family
Programmer
Tools
View
Help
PIC18F Configuration
Device: PIC18F8520
Configuration: 2600 0E0F 0183 0081 C00F E00F 400F
User IDs: FF FF FF FF FF FF FF FF
Checksum: DEED
OSCCAL:
BandGap:
Programming Successful.
MICROCHIP
VDD Target
Check
/MCLR
5,0
Read
Write
Verify
Erase
Blank Check
Program Memory
Enabled
Hex Only
Source: C:\...uator_hibu_2012\Software\MCC\MCC.hex
0000 EF5E F01B FFFF 003C C000 F023 C001 F022
0010 C002 F021 C003 F020 C004 F01F C005 F01E
0020 C006 F01D C007 F01C C008 F01B C009 F01A
0030 C00A F019 C00B F018 C00C F017 C00D F016
0040 C00E F015 CFF3 F024 CFF4 F025 A09E D01B
0050 0E00 5C5A E102 0E02 5C59 E30C EC67 F018
0060 EC41 F018 EC8D F018 ECF3 F01A ECC0 F018
0070 6A59 6A5A 4A57 2A58 4A59 2A5A 0EAF 6ECE
0080 0E3C 6ECF 909E C024 FFF3 C025 FFF4 C023
0090 F000 C022 F001 C021 F002 C020 F003 C01F
00A0 F004 C01E F005 C01D F006 C01C F007 C01B
00B0 F008 C01A F009 C019 F00A C018 F00B C017
EEPROM Data
Enabled
Hex Only
000 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
010 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
020 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
030 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
Auto Import Hex + Write Device
Read Device + Export Hex File
PICkit 2

Figure 4: PICkit2 programmer software

Open file and choose import hex. Navigate to the hex file created by MicroC. Press OK and you should get a hex file successfully loaded.

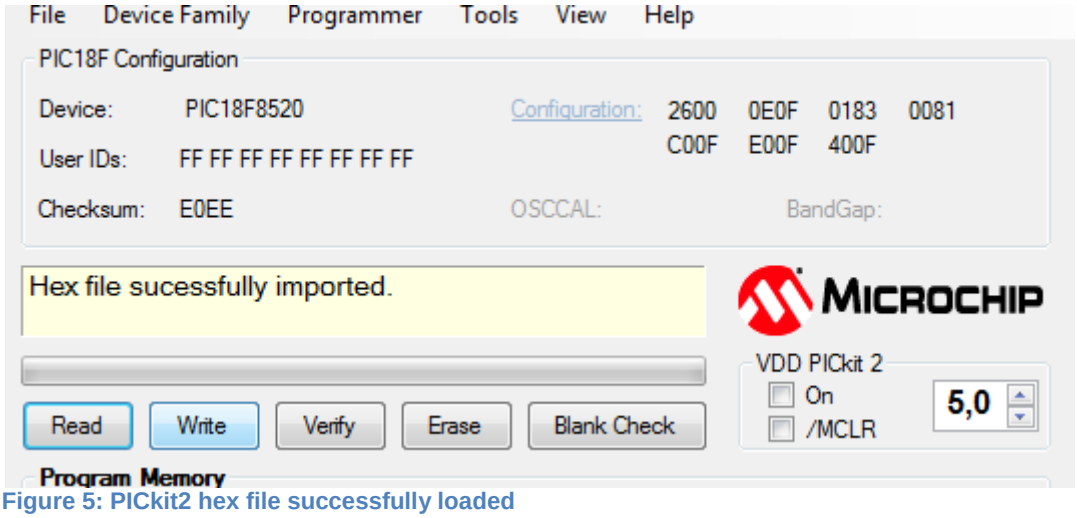

Figure 5: PICkit2 hex file successfully loaded

You can now press write and the hex file gets loaded into the PIC controller.
It is recommended to restart the PIC after the code has been loaded to get a clean start-up.

3.2.3. Where to find Information?

Documents we used a lot while developing the system:

- Wiring Diagram for MCC: Here you can see where every wire is connected on the MCC and which pin on the PIC that goes to which connector.
- Card Configuration: This is a great reference for programmers! It is an Excel sheet with explanation on which pins that are used on the microcontrollers and what they interface with.
- Schematic for MCC: Self-explanatory, a schematic for the PCB.
- PCB-Layout MCC: This requires the user to have the Proteus PCB Design Package, but is a great way getting to know the PCB card, and troubleshooting the circuit.

3.3. The Supervisor

3.3.1. Introduction

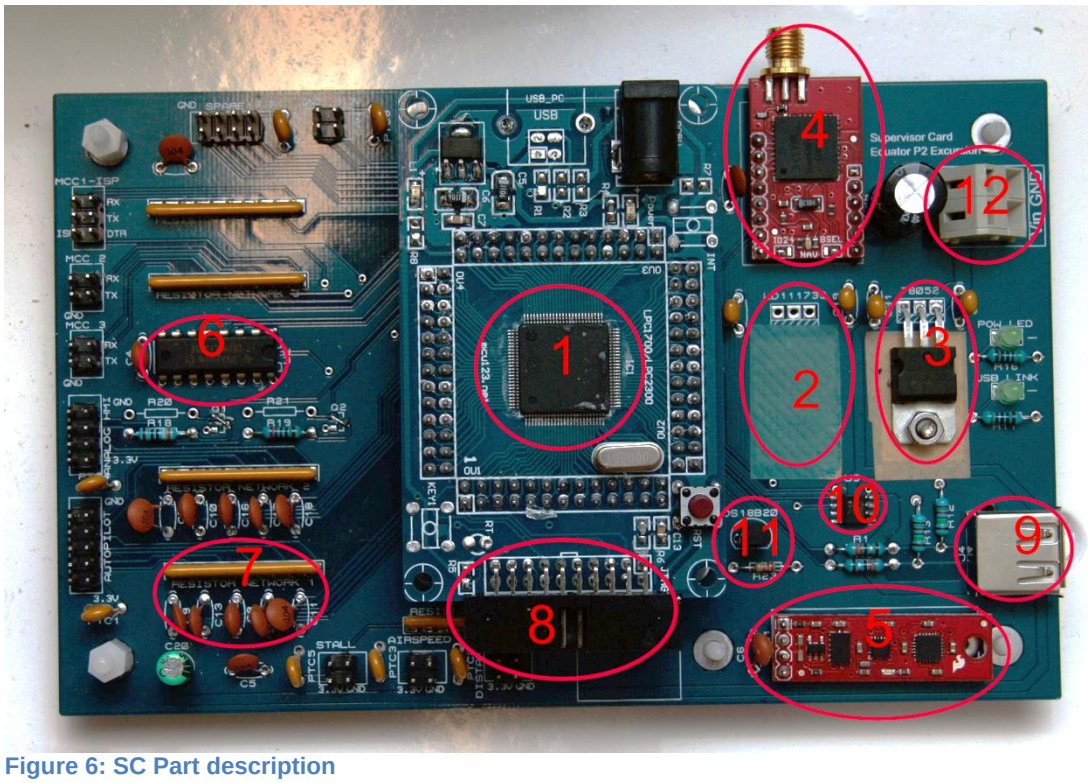

Figure 6: SC Part description

1. LPC1768 Cortex m3 microprocessor. When we received this core board there was some buttons and sensors on it which had to be removed since we use these pins on out PCB.
2. 3.3Volt 800mA regulator.
3. 5V regulator for charging USB device and level conversion.
4. GPS device
5. IMU device(magnetometer, Gyroscope and accelerometer)
6. Level conversion for communication(TX from 3.3 to 5v)
7. RC filter
8. JTAG for programming
9. USB Connector
10. USB charge controller
11. Temperature sensor, One Wire
12. Power Connector

3.3.2. Where to find Information?

Documents we used a lot while developing the system:

- Wiring Diagram for SC: Here you can see where every wire is connected on the SC and which pin on the LPC1768 that goes to which connector.
- Card Configuration: This is a great reference for programmers! It is an Excel sheet with explanation on which pins that are used on the microcontrollers and what they interface with.
- Schematic for SC: Self-explanatory, a schematic for the PCB.
- PCB-Layout SC: This requires the user to have the Proteus PCB Design Package, but is a great way getting to know the PCB card, and troubleshooting the circuit.

3.3.3. Software

The code development for the supervisor is done using Keil compiler. The program can be downloaded from here: http://www.keil.com/download/product/
The demo version has a 32kB limit that is sufficient for our use so a license will not be supplied with the product. A user manual for the keil compiler is found here: http://www.keil.com/support/man/

To get the software loaded into the LPC ARM controller it is necessary to use a programmer/debugger. The ULINK programmer/debugger will be supplied with the compact fly by wire product. The USB cable connects to your computer and the other end connects to JTAG port on the supervisor see part 8 on Figure 6.

To compile the code press the button. To upload the code, press the

button. The code is then loaded into the LPC controller. The supervisor card needs to be restarted after the code is uploaded.

3.3.4. Where to find Information?

Documents we used a lot while developing the system:

- Wiring Diagram for SC: Here you can see where every wire is connected on the SC and which pin on the LPC1768 that goes to which connector.
- Card Configuration: This is a great reference for programmers! It is an Excel sheet with explanation on which pins that are used on the microcontrollers and what they interface with.
- Schematic for SC: Self-explanatory, a schematic for the PCB.
- PCB-Layout SC: This requires the user to have the Proteus PCB Design Package, but is a great way getting to know the PCB card, and troubleshooting the circuit.

3.4. Simulator

To the system it is programmed a software code in Arduino IDE and a XML-file for communicate with an open source flight simulator called FligtGear. This simulator can be downloaded from FlightGears homepage:
http://www.flightgear.org/ (16.05.2012)

The software code and the XML file can be found in the: Software folder

The aircraft that the code is made for is not a part of the original aircraft library. This aircraft is called “Long EZ” and can be downloaded from the page:
http://www.flightgear.org/download/aircraft-v2-4/ (16.05.1012)
To implement this in FlightGear, find the FlightGear folder on your computer and unzip the downloaded folder to FlightGear/Data/Aircraft.

The XML code should be placed in the folder Flightgear/data/Protocol

After finishing the downloading, connect the Arduino microcontroller to you PC and push the Flightgear Icon shown under, to start the simulator.

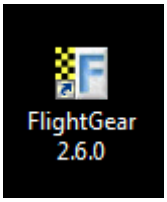

Figure 1: Icon for flightgear

When FlightGear starts, you get the screen sown under. Here select the aircraft “Rutan Long EZ” and push next.

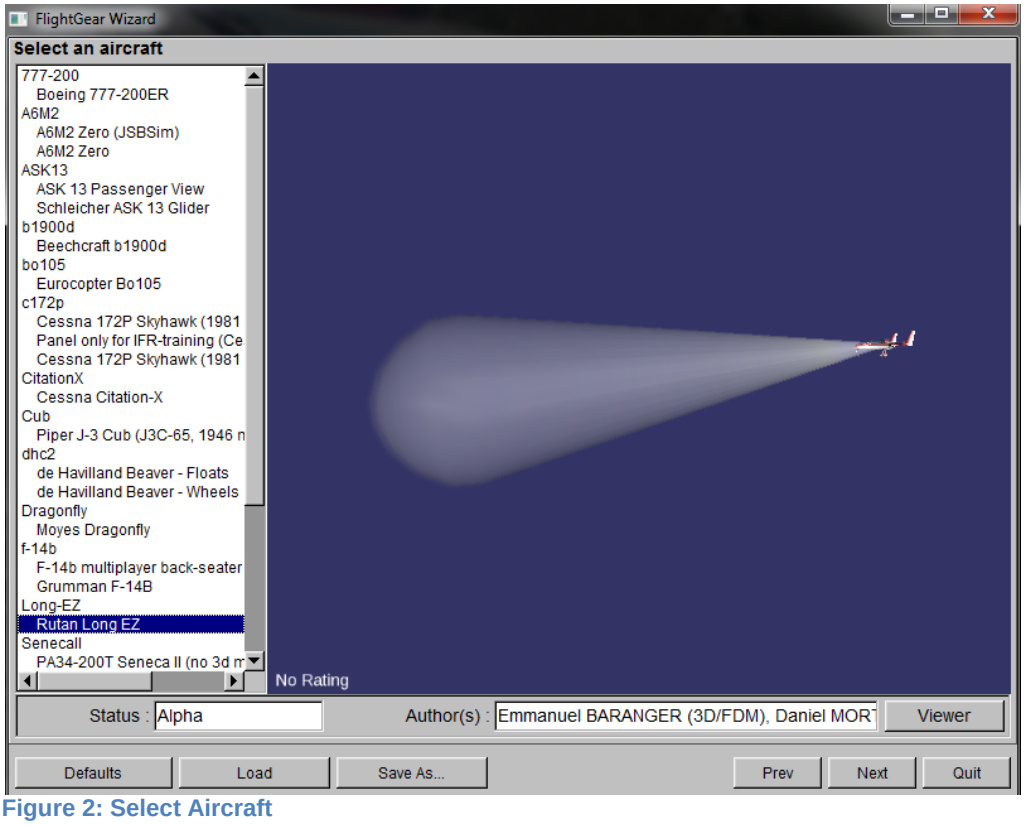

Figure 2: Select Aircraft

The next step is to choose a location where you want to fly, here you can choose the one you want, and push next.

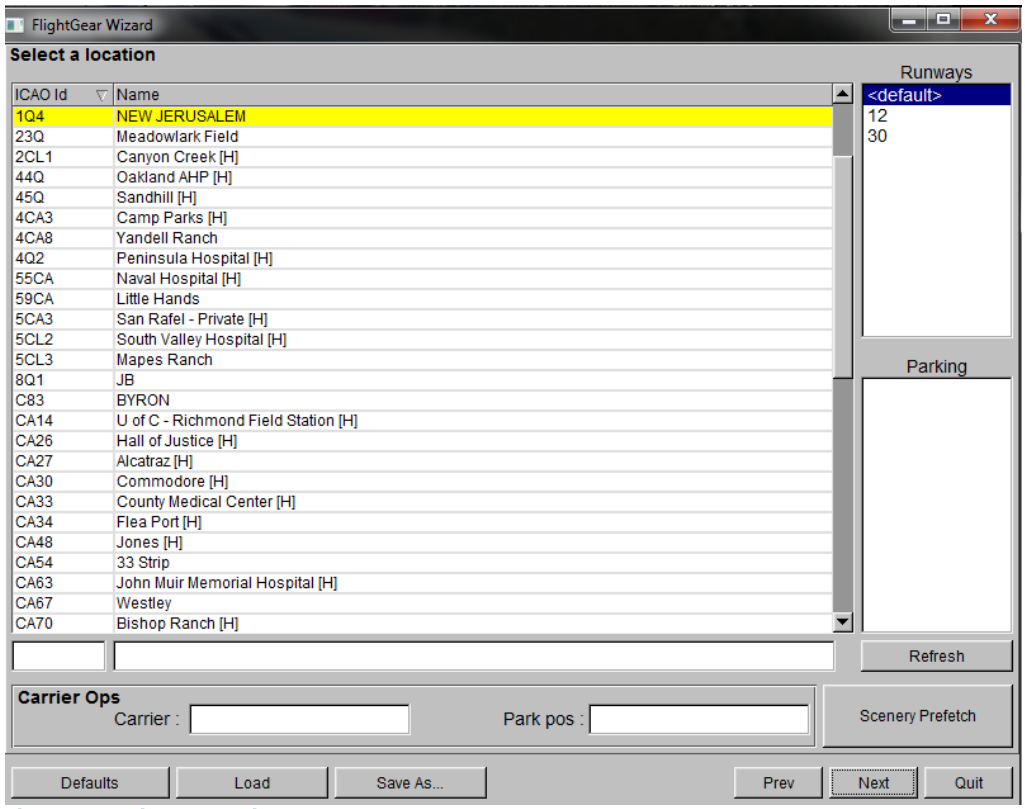

Figure 3: Select Location

In the next screen picture it is possible to set different condition, and it is here you have to implement the XML code. For doing this, select “Advanced.”

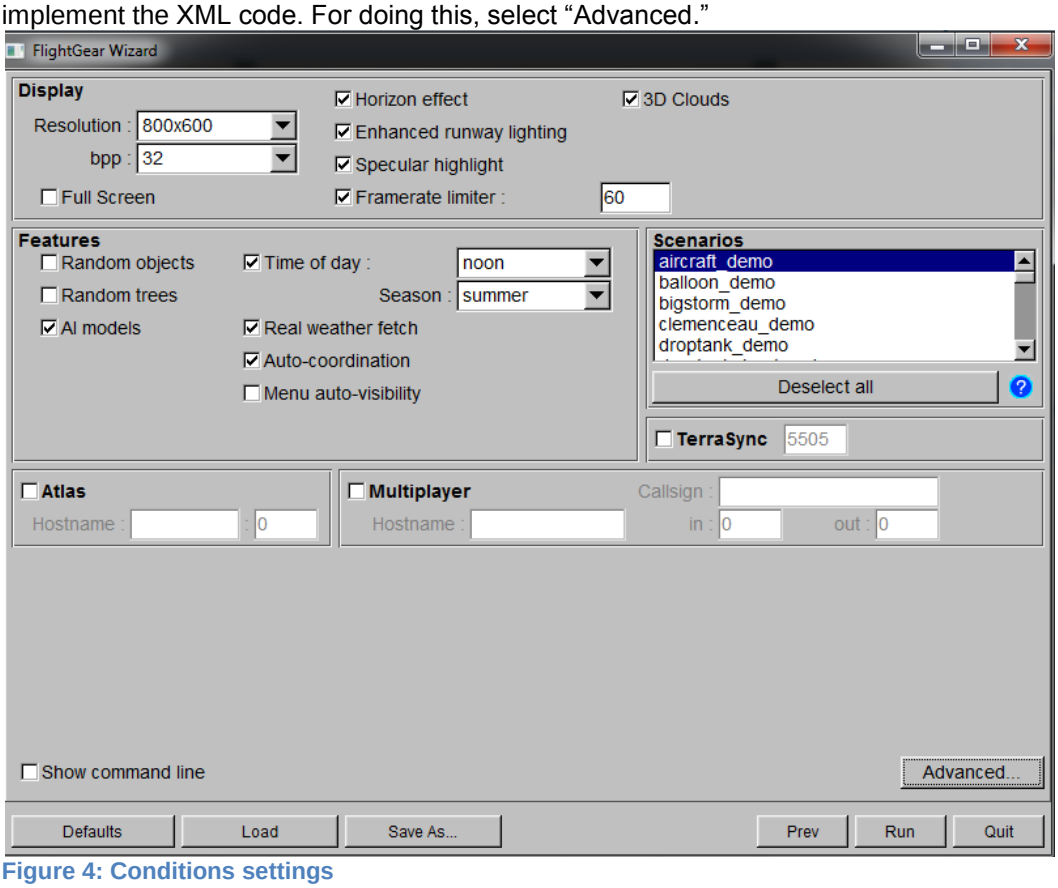

Figure 4: Conditions settings

In the advanced menu choose Input/Output on the left hand side of the screen. The developed code is based on serial communication and the protocol that has been used is Generic. The direction of the serial data should be in and the frequency can be chosen after how often you want to read the incoming data. To know which Port you shall use, you have to check which comport the Arduino microcontroller is connected to. The baud rate used in the developed code is 9600, so it is important to use this baud rate in FlightGear too. One the last option you shall choose the developed XML-code that you past in the folder "protocol." No push ok then run.

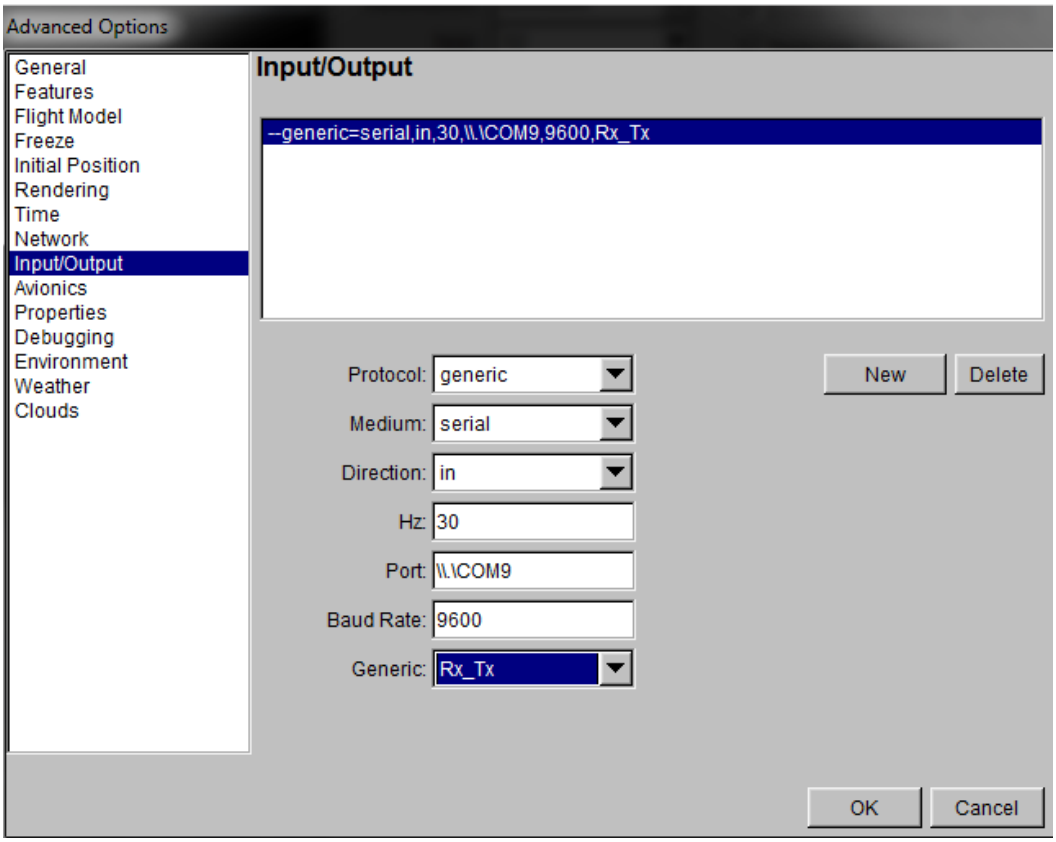

Figure 5: Advanced Options

FlightGear is no running, and screen in figure 6 is shown. If everything is correctly done, the simulator is ready to be used. If there is an error, the loading screen in figure 6 will "not respond" and the simulator does not start. Then it can be an idea to start FlightGear with nothing added in figure 5, just delete the Input/Output properties. This to be sure that the PC is able to run FlightGear.

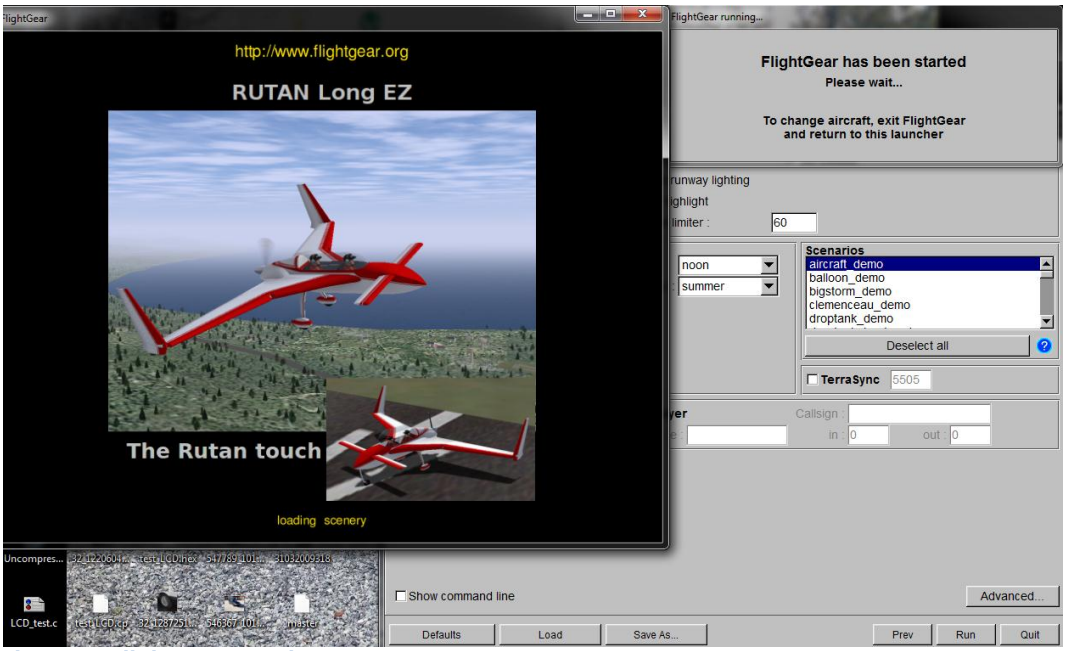

Figure 6: FlightGear running

When the FlightGear is running, it is possible to check the parameters we want to control. To check this, go to Debug on the top line, and choose Browse Internal Properties. You will now get the screen shown in figure 7.

Figure 7: Browse Internal Properties

All the flaps parameters can be found under controls/flight. These parameters shall respond to the motion of the joystick

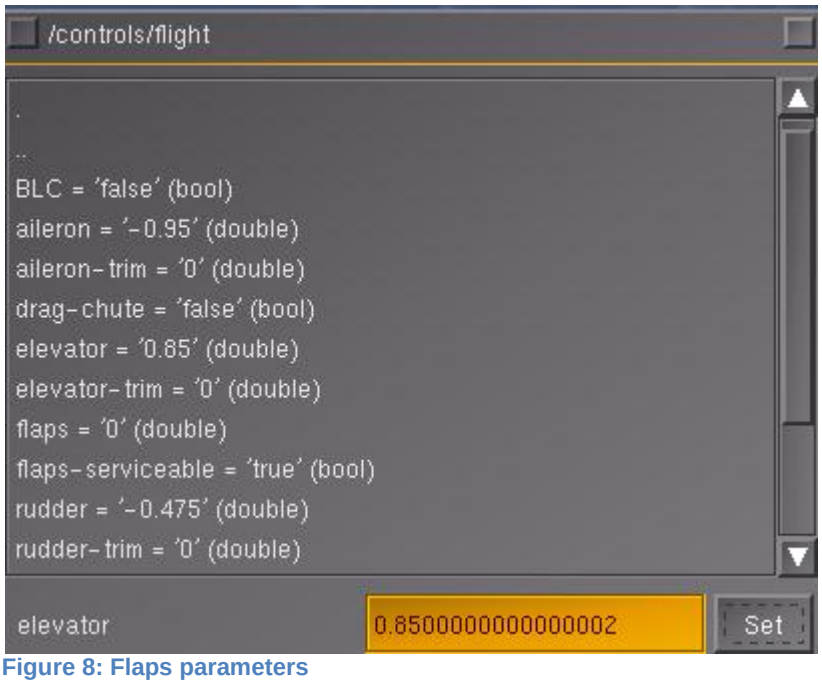

Figure 8: Flaps parameters

4. FURTHER INFORMATION

For a more detailed explanation of the functions please read:

- SW description
- HW description

For information on how to assemble the system and troubleshooting please read:

- System topology
- MCC wiring diagram
- SC wiring diagram
- HMI wiring diagram

4.1.1.1. Contact

For further assistance please do not hesitate to contact Equator Aircraft Norway on:

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e-mail: mail@equatoraircraft.com

phone: (+47) 970 39 469

Visit: Brugata 11
0186 Oslo
Norway

Post address: Maridalsveien 64C
0458 Oslo
Norway

Hardware Description

Version	1.0
Category	Released
Issue Date	26.05.2012
Made by	A.G
Checked by	O.R
Approved by	A.G

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1. PURPOSE

The purpose of this document is to learn how our system works and go into detail on each component and unit on the MCC and the SC PCB's, to specify the I/O ports needed on the PIC18F8520. Make a piggyback for the units and to find out the voltage each component and unit needs, and also to identify the MTBF on each components in order for us to calculate the MTBF of the MCC and the SC, and off course the whole system.

2. ABBREVIATION

Technical Term	Standard Definition
K.M.	KjetilMjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	RunarLøken
O.R.	Ole Riiser
MCC	Main Controller Card
SC	Supervision Card
MCU	Microcontroller Unit
MIPS	Million Instructions Per Second
EEPROM	Electrically Erasable Programmable Read-Only Memory
USART	Universal Synchronous/ Asynchronous Receiver/Transmitter
PWM	Pulse-Width Modulation
CCP	Capture/Compare/PWM
MTBF	Mean Time Between Failure
IMU	Inertial measurement Card

3. TEMPLATE

3.1.1. Name:

Schematic drawing:		
Description		
Function		
I/O specification	Specify the inputs and the outputs needed on the PIC18	
V_{in} & I_{max}		
MTBF		
Footprint		
Price		
References		
Author / date		

4. SYSTEM DIAGRAM

The system we make is a replacement for the old manual steering system for light airplanes. It is supposed to mimic the movements that the old system has but also prevent critical pilot errors like stall angle etc. The system can also be implemented with autopilot etc. for computer assisted flight.
The system (Figure 1) consists of three Main controller cards (MCC) which by itself can control the airplane alone. But because we don't always trust electronics we make the system triple redundant. They get joystick readings from a triple redundant joystick which has three axes and has their own stepper controller for actuation of the control surfaces. The stepper motors on the control surfaces has a really high life expectancy so they don't need redundancy.
The three MCCs needs supervision so they do not overrides each other and this is why we have the supervisor card (SC). The supervisor card receives information from all the MCCs and decides which MCC to be in control of the control surfaces. The SC also contains a lot of sensors for measuring the planes orientation, velocity and height which can be used as pilot assistance and reference for autopilot. The sensors we have included are:

Internal sensors:

- Accelerometer
- Gyroscope
- Magnetometer
- Barometer
- GPS

External sensors

- Ultrasonic range sensor
- Airspeed sensor
- Angle of attack sensor

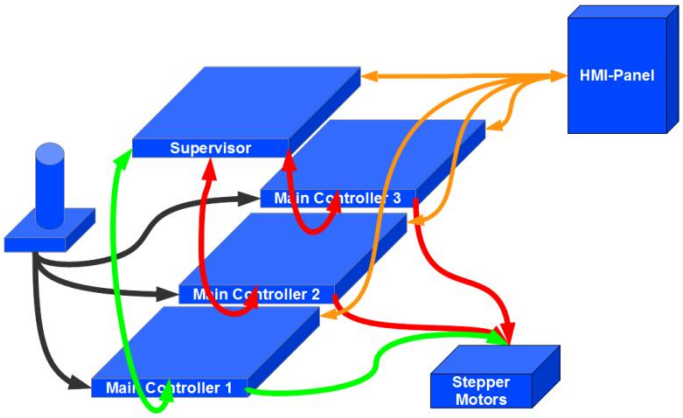


Figure 1: System diagram

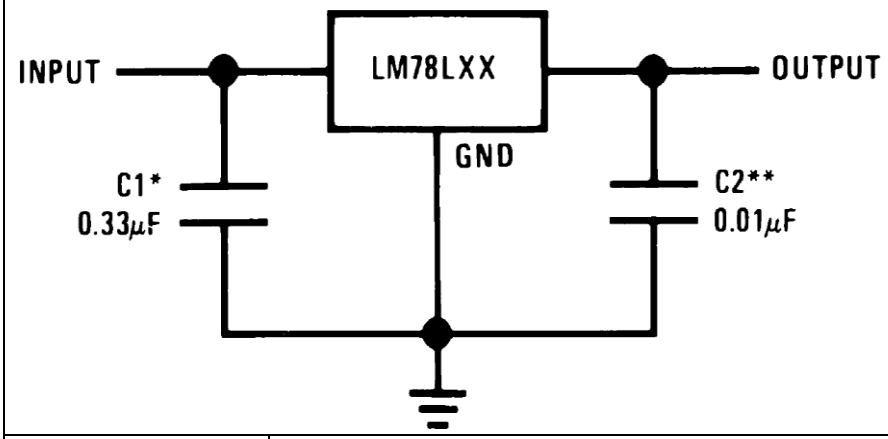
5. MAIN CONTROLLER CARD

See:
Appendix 5; MCC Wiring Diagram
Appendix 2; MCC Overview

5.1. Power Supply Unit

5.1.1. Linear Voltage Regulator 5V (LM 78L05)

Schematic drawing:



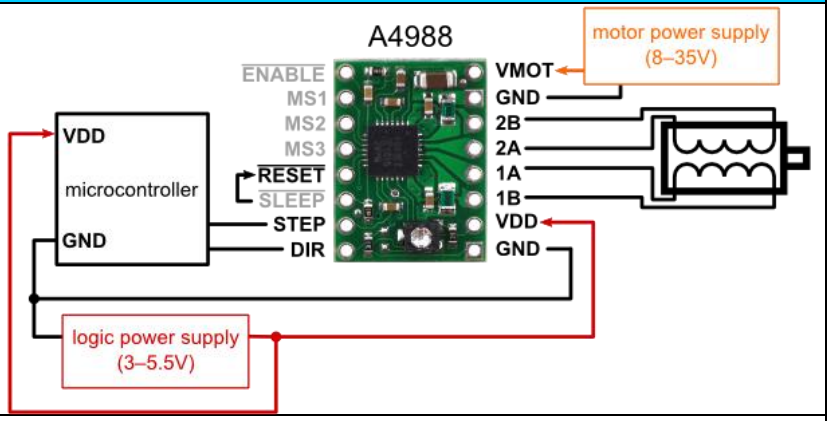
Description	We have changed this regulator from a switching regulator since the estimated current consumption of the board is a lot less than expected. We have estimated that the board will draw approximately 150mA, which will produce 1.35watts of heat, we consider using the ground plane as a heat sink.	
Function	Deliver a steady power supply to the logic circuits as well as the LEDs used. (5V ±0.2V).	
I/O specification	**Input**	**Output**
	13.8V ±4V	5V ± 0.2V
	GND	N/A
V_{in} & I_{max}	$7.9V_{min}$ – $35V_{max}$ & load currents up to 1000mA	
MTBF	1002356520 hours	
Footprint	TO-92	
Price	1 USD	
References	7.1.1.4 LM 78L05 data sheet	
Author / date	O.R	20.03.2012

Figure 2: Connectors On MCC

5.2. Stepper Controller

5.2.1. A4899 Stepper motor driver

Schematic drawing:



Description	Each Stepper controller is controlling one stepper motor; it is five stepper controllers on each MCC controlling the Nose wheel, rudder, right aileron, left aileron and the elevator.	
Function	The stepper controller will amplify and convert a directional pulse from the PIC18F8520 to a current signal to the motor, controlling the speed and direction. The stepper controller will be enabled or disabled by the PIC18. And can be reset if desired.	
I/O specification	**Output: PIC18F8520**	**Input: A4899**
	Ref: MCC Card configuration	STEP
	Ref: MCC Card configuration	RESET
	Ref: MCC Card configuration	DIR
	Ref: MCC Card configuration	ENABLE
	13.8V	VMOT
	GND	GND
	5V	VDD
	GND	GND
	Output: A4988	**Stepper motor:**
	1A	Red
	1B	Yellow
	2A	Orange
	2B	Blue
V_{in} & I_{max}	8 – 35 V_{in} & maximum 2A per coil (2 coils = 4A)	
MTBF	31,784.5 hours	
Price	12.95 USD	
References	7.1.1.5 data sheet of the A4988	
Author / date	A.G and R.L	07.03.2012

5.3. Sensors

5.3.1. Temperature DS18B20

Picture:

Description	This device will give us the temperature of the Card specified.	
Function	This sensor gives us a calibrated reading without the need for a analog input. The sensor uses a One wire protocol that gives a string of data upon request.	
I/O specification	Connected to a 1-wire bus.	
V_{in} & I_{max}	5v	
MTBF	-	
Footprint	TO-92	
Price	2 USD	
References	http://datasheets.maxim-ic.com/en/ds/DS18B20.pdf	
Author / date	O.R	23.05.2012

6. SUPERVISOR CARD

The Supervisor card is the card that decides which of the Main controller cards that is active. The Supervisor card can also be implemented with autopilot and can be connected to an android tablet. The Supervisor receives status information from all the MCCs and compares them to each other. This si also the controller that communicates with the user.

6.1.1. Linear Voltage Regulator 3.3V (LD111733)

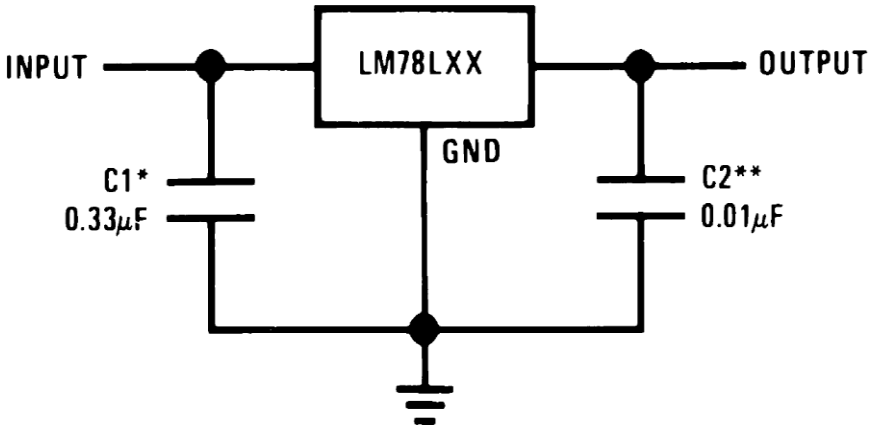
Picture:

Description	The LPC1768 Is Running at 3.3 Volt and Therefore we use this Voltage Regulator. It can Supply 800mA of current
Function	Deliver a steady power supply to the joystick (5V ±0.2V).

I/O specification	Input	Output
	13.8V ±4V	3.3V ± 0.033V
	GND	N/A
V_{in} & I_{max}	$7.9V_{min}$ – $18V_{max}$ & load currents up to 1000mA	
MTBF	1002356520 hours	
Footprint	TO-220(NOT standard pinout!!)	
Price	1 USD	
References	7.1.1.4 LM 78L05 data sheet	
Author / date	A.G	09.02.2012

6.1.2. Linear Voltage Regulator 5V (LM 78L05)

Schematic drawing:



Description	This power supply will provide some 5v circuitry with 5v, like logiv level converter and USB charging Current.	
Function	Deliver a steady power supply to the joystick (5V ±0.2V).	
I/O specification	**Input**	**Output**
	13.8V ±4V	5V ± 0.2V
	GND	N/A
V_{in} & I_{max}	$7.9V_{min}$ – $35V_{max}$ & load currents up to 1000mA	
MTBF	1002356520 hours	
Footprint	TO-220	
Price	1 USD	
References	7.1.1.4 LM 78L05 data sheet	
Author / date	A.G	09.02.2012

6.2. Microcontroller

6.2.1. LPC1768

Schematic drawing:

Description	The LPC1768 is a 32-bit microcontroller which is much better for this board than the PIC18F8520. We use a Core-board solution which has J-tag connector breaked out

	and we don't need to solder surface mount components. http://www.wayengineer.com/index.php?main_page=product_info&products_id=200	
Function	Monitor every MCC and decide which that has control over the system.	
I/O specification	"*The LPC1768 microcontroller has 512KB of internal flash and 64KB RAM. Ethernet MAC, USB Device/Host/OTG interface, 8-channel general purpose DMA controller, 4 UARTs, 2 CAN channels, 2 SSP controllers, SPI interface, 3 I2C-bus interfaces, 2-input plus 2-output I2S-bus interface, 8-channel 12-bit ADC, 10-bit DAC, motor control PWM, Quadrature Encoder interface, 4 general purpose timers, 6-output general purpose PWM, ultra-low power Real-Time Clock (RTC)*" http://www.sparkfun.com/products/9931	
Price	20USD:	
References	ics.nxp.com/products/lpc1000/datasheet/lpc177x.lpc178x.pdf	
Author / date	O.R	16.04.2012

6.3. Sensors

6.3.1. IMU

Schematic drawing: http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/IMU/9DoF-Stick-v13.pdf (Author Sparkfun electronics, Last Read 13.02.2012)		
Description	This is a sensor card that will give us information about the position of the plane and where it's heading. This module has an accelerometer, gyroscope and a magnetometer (Compass) built in. Module made by Sparkfun Electronics.	
Function	Gives us data about heading direction(Magnetometer), angular velocity in three dimensions(Gyroscope) and acceleration forces in three axis(Accelerometer)	
I/O specification	I2C Bus, has a built-in 3.3v regulator	
V_{in} & I_{max}	16v	
Footprint	4 connector holes with 0.1" spacing	
Price	99USD	
References	http://www.sparkfun.com/products/10724 (last read 13.02.2012)	
Author / date	O.R	13.02.2012

6.3.2. GPS

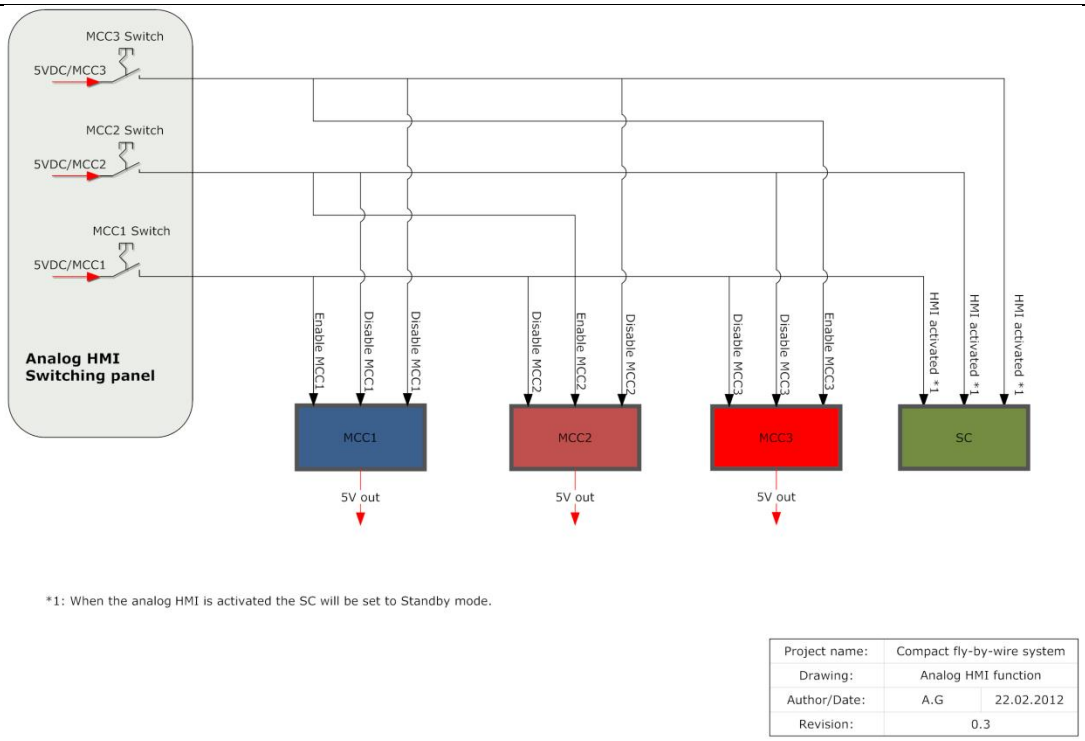
Schematic drawing: **http://www.sparkfun.com/datasheets/GPS/Modules/Venus_GPS-v15sma.pdf** (Author SparkFun Electronics, Last Read: 13.02.2012)	
Description	This is a GPS module that will give us positioning data, height, ground speed and clock.
Function	Gives positioning data, height, ground speed, and time.
I/O specification	This device communicates over a serial line and will be connected t the multiplexer described in this document(**Error! Reference source not found.**)
V_{in} & I_{max}	3.3v regulated, 29mA load current
Footprint	Four connector holes with 0.1" spacing
Price	49 USD

References	http://www.sparkfun.com/products/11058	
Author / date	O.R	13.02.2012

7. ANALOG HMI

7.1.1. Analog HMI switches

Schematic drawing:

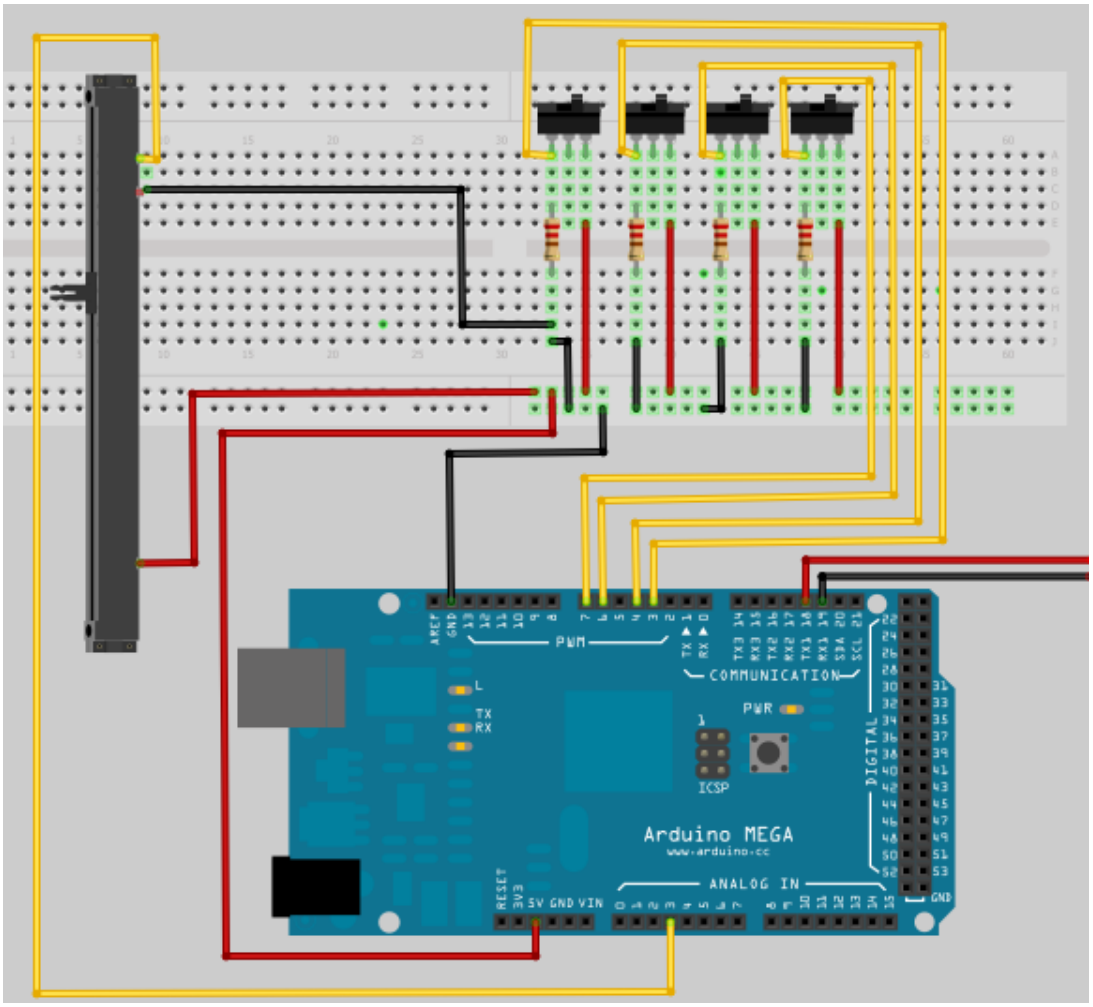


Description	The analog HMI switches should only be used if the SC is not responding or is acting strange.		
Function	If MCC 1 switch is pressed down, the 5V signal from the MCC1 will be sent to the "enable" port on the MCC1, and it will go to operational state. At the same time a signal is sent to MCC2 & MCC3 telling them that MCC1 is in control, and they will go to standby mode. The same signal will go to the SC telling it that the analog HMI is activated, and the SC will go to standby. Same function for the MCC2 & the MCC3 switch.		
I/O specification	**Power supply**	**Switch**	**Input**
	5V from MCC1	MCC1	Enable MCC1
	5V from MCC1	MCC1	Disable MCC2
	5V from MCC1	MCC1	Disable MCC3
	5V from MCC1	MCC1	HMI activated
	5V from MCC2	MCC2	Enable MCC2
	5V from MCC2	MCC2	Disable MCC1
	5V from MCC2	MCC2	Disable MCC3
	5V from MCC2	MCC2	HMI activated
	5V from MCC3	MCC3	Enable MCC3
	5V from MCC3	MCC3	Disable MCC1
	5V from MCC3	MCC3	Disable MCC2
	5V from MCC3	MCC3	HMI activated
V_{in} & I_{max}	V_{in} = 5V from MCC1, MCC2 or MCC3		
MTBF	N/A		
Price	N/A		
References	N/A		
Author / date	A.G	22.02.2012	

8. SIMULATOR

8.1.1. Simulator hardware

Schematic drawing:



Description	To the simulator communication we use a Arduino Mega microcontroller. This is connected the way the drawing shows with 4 switches that turns the different parameters on and off. The serial lines are used to send data, and the slide potmeter is used for throttle.
I/O specification	Digital Pin 3, =Gear down Digital Pin 4 = Magnetos Digital Pin 6 = Start engine Digital Pin 7 = Brake Analog Pin 3 = Throttle Pin 18 = Possible to send data from Flightgear to our system Pin 19 = Receive data from our system USB port = sending data to Flightgear from Arduino Mega
Price	67 USD
References	Arduino Mega 2560 user manual

	http://arduino.cc/en/Main/ArduinoBoardMega2560 Last read 15.05.2012	
Author / date	Runar Løken	15.05.2012

9. REFERENCES

9.1. MCC

9.1.1.1. MCU Cards for BIGPIC5™ development systems

Data sheet for the PIC18F8520 piggyback
Author: Micro Electronika
Last read: 09.02.2012 by A.G

9.1.1.2. PIC18F6520/8520/6620/8620/6720/8720

Data sheet for the PIC18F8520
Author: Microchip
Last read: 09.02.2012 by A.G

9.1.1.3. LM78LXX Series 3-Terminal Positive Regulators

Data sheet for the LM78L05 PSU
Author: Texas Instruments Copyright 15th of January 2012
Last read: 09.02.2012 by A.G

9.1.1.4. A4988 Data sheet

Data sheet for the A4988 stepper controller
Author: Allegro Microsystems, Inc.
Last read: 10.02.2012 by A.G

9.1.1.5. DS18B20 temp sensor

Datasheet:
http://datasheets.maxim-ic.com/en/ds/DS18B20.pdf
Author: Maxim, Copyright 2008
Last Read: 13.02.2012

9.2. SC

9.2.1.1. IMC

Error! Reference source not found. Picture:
HYPERLINK "http://dlnmh9ip6v2uc.cloudfront.net/images/products/10724-01b.jpg"
http://dlnmh9ip6v2uc.cloudfront.net/images/products/10724-01b.jpg

Accelerometer datasheet:
http://www.sparkfun.com/datasheets/Sensors/Accelerometer/ADXL345.pdf

Author: Analog Devices Copyright 2009
Last Read: 13.02.2012

Gyro datasheet: http://www.sparkfun.com/datasheets/Sensors/Gyro/PS-ITG-3200-00-01.4.pdf

Author: InvenSense Copyright 2009
Last Read: 13.02.2012

Magnetometer datasheet:

http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Magneto/HMC5883L-FDS.pdf

Author: HoneyWell Copyright 2010

Last Read: 13.02.2012

9.2.1.2. GPS

Product Link: http://www.sparkfun.com/products/10921 Last Read: 13.02.2012
GPS-Datasheet:
http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/GPS/Venus638FLPx.pdf
Author: SkyTrack Technology Copyright 2008. Version 0.7
Last Read 13.02.2012

10. REVISIONS

Responsible person for this document, procedure or template

Rev	Description	Date	Name:
0.1	Made the template, wrote the purpose, updated references Made: 5.1.1 LM2596, 5.1.2 LM78L05,	09.02.2012	S.A / A.G
0.2	Made: 4.3.1 Temperature DS18B20, 5.2.1 744052, 5.3.1 IMC, 5.3.2 GPS	10.02.2012	O.R / A.G
0.3	Made: 6.1.1 analog HMI	22.02.2012	A.G
0.4	Updating 4.2 stepper controller	07.03.2012	R.L
0.5	Changed document name and filled in overview	19.03.2012	O.R
0.6	Changed main PSU 5.1.1	20.3.2012	O.R
0.7	Making chapter for simulator hardware	15.05.2012	R.L
0.8	Updated the document	23.05.2012	O.R/A.G
1.0	Official release	23.05.2012	A.G

HARDWARE RESEARCH DOCUMENT

Compact Fly By Wire System

Version	1.0
Category	Released
Issue Date	22.05.2012
Made by	O.R
Checked by	A.G
Approved by	Knut brødreskift

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2. SCOPE

This document will contain detailed information about the choices of components we make during the project.

3. PURPOSE

We made this document to get a complete overview over the current and faulted components. The overview contains information about why we chose the components, what they do, positive/negative aspects, time spent and which component the new one replaces. The purpose is to show and explain why we chose a specific component over another one that has the same functionality. This document is also useful for looking at key functions of the component and where it is used in the system.

4. ABBREVATION

Technical Term	Standard Definition
K.M.	KjetilMjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	RunarLøken
O.R.	Ole Riiser
MCC	Main Controller Card

SC	Supervision Card
MCU	Microcontroller Unit
MIPS	Million Instructions Per Second
EEPROM	Electrically Erasable Programmable Read-Only Memory
USART	Universal Synchronous/ Asynchronous Receiver/Transmitter
PWM	Pulse-Width Modulation
CCP	Capture/Compare/PWM

Table 1: Abbreviation

5. HARDWARE RESEARCH TEMPLATE

5.1.1. **Name of the component**	
Part of	
Background	
Critical component function	
Positive aspects	
Negative aspects	
Time spent(Hours)	
Replaces	
Reference	
Owner and date	

Table 2: Hardware research template

6. HARDWARE GROUPS

6.1. Production

6.1.1. **Printline.dk**	
Part of	Production of the card
Background	We need to decide for which producer who will print our circuit
Critical component function	Fast delivery and quality production
Positive aspects	Fast delivery, multi-layer production
Negative aspects	N/A
Time spent(Hours)	1
Replaces	6.1.2
Reference	www.printline.dk 13.01.2012
Owner and date	S.A 13.01.12

Table 3: Option 6.1.1

6.1.2. **Elprint.no**	
Part of	Production of the card
Background	We need to decide for which producer who will print our circuit
Critical component function	Fast delivery and quality production
Positive aspects	Fast delivery, multi-layer production
Negative aspects	N/A
Time spent(Hours)	1
Replaces	N/A
Reference	www.elprint.no 13.01.2012
Owner and date	S.A 13.01.12

Table 4: Option 6.1.2

6.1.3. **PCBCart.com**	
Part of	Production of the card
Background	We need to decide for which producer who will print our circuit
Critical component function	Fast delivery and cheap production
Positive aspects	Fast delivery and cheap production
Negative aspects	N/A
Time spent(Hours)	1
Replaces	6.1.2
Reference	www.pcbcart.com 03.05.2012
Owner and date	O.R 03.05.2012

6.2. Communication

6.2.1. **Serial communication USART**	
Part of	Communication between units
Description	By using this method we are able to send as much info as we want to the SC. Example about info that can be sent: - MCC number sending - X-Y-Z joystick input - X-Y-Z calculated control signal to stepper controller - Time used for calculating output signal - MCC card temperature - Checksum A typical example of a serial package: $2,522,522,522,34,34,34,45,3*

Critical component function	Communication and “lifeline” for MCC to SC
Positive aspects	Fast speed, 19200bps. Simple, well-known, has been a standard for decades. Start en end message character for added security. Checksum number for confirmation that the correct number of bits is received. A “lifeline” can be implemented by using a counter that counts the time since last received data. If no data is received in a predefined time period it is reasonable to assume that the MCC is down. All the info sent makes it easy to pinpoint an error. The bandwidth of the serial wires is bigger than the parallel wires. “If, however, we bump up the power in a serial connection by using a differential signal with 2 wires (one with a positive voltage, and one with a negative voltage), we can use the same amount of power, have twice the SNR, and reach an even higher bitrate without suffering the effects of noise.”
Negative aspects	Data may be corrupted. A little out-dated, problems with communication between devices that have separate power supplies,
Time spent(Hours)	4
Replaces	N/A
Reference	http://en.wikipedia.org/wiki/RS-232 23.01.2012 http://www.edaboard.com/thread229518.html 23.01.2012 http://en.wikibooks.org/wiki/Communication_Networks/Parallel_vs_Serial 06.02.2012
Owner and date	K.M & S.A 06.02.2012

6.2.2. **Parallel data**

Part of	MCC and SC
Description	Example about info that can be sent: - Pulsating signal indicating that the MCC is live and working - Binary status updates
Critical component function	Communication and “lifeline” for MCC to SC
Positive aspects	Easy “lifeline” communications with a pulsating input
Negative aspects	Limited information can be sent. Takes up more pins on both the MCC and SC. Suffers from inter-symbol interference and noise over long distances. The bandwidth of the parallel wires are smaller than the serial wires. “Because of the increased potential for noise and interference, parallel wires need to be far shorter than serial wires”
Risk Profile	May cause confusion to the system if lines are disconnected.
Time spent(Hours)	3
Replaces	N/A
Reference	http://en.wikipedia.org/wiki/Parallel_communication 30.01.2012 http://en.wikibooks.org/wiki/Communication_Networks/Parallel_vs_Serial 06.02.2012
Owner and date	K.M & S.A 06.02.2012

6.3. Communication between all MCCs and SC

6.3.1. **Multiplexer**	
Part of	SC
Background	On the PIC18F8520 there is only two UARTS and we need the SC to communicate with five units with serial interface. This we can accomplish by using a multiplexer.
Critical component function	The multiplexer need to be easily controllable for both TX and RX. The 744052 has two four channel multiplexers which is optimal for our use.
Positive aspects	We get all the serial communication we need with a simple interface.
Negative aspects	Extra component which will decrease the MTBF.
Time spent(Hours)	3
Replaces	N/A
Reference	http://www.taydaelectronics.com/datasheets/A-027.pdf visited 09.02.2012
Owner and date	O.R 09.02.2012

6.3.2. **New controller (LPC1768)**	
Part of	SC
Background	On the old Controller (PIC18F8520) there was only two UARTS. We decided to change this controller of many reasons. Which this was one of them.
Critical component function	It has four UARTS which all has its own buffer, this makes is easier to operate
Positive aspects	We get all the serial communication we need with a simple interface. Fewer components than the above solutions.
Negative aspects	Extra component which will decrease the MTBF.
Time spent(Hours)	3
Replaces	6.3.1
Reference	
Owner and date	O.R 16.05.2012

6.4. Cables

6.4.1. 0.25mm2 copper cable

Part of	MCC and joystick
Background	In order to prevent a significant voltage loss in the cables
Critical component function	Conduct electricity
Positive aspects	Only 0.0018174V drop when: 5V power supply, at a 3mA current, and maximum 8m distance at 30˚C.
Negative aspects	No shielding
Time spent(Hours)	2
Replaces	N/A
Reference	https://www1.elfa.se/data1/wwwroot/assets/datasheets/05540000.pdf 25.01.2012
Owner and date	A.G 23.01.2012

6.5. Shielding

6.5.1. No shielded cables for power and signal

Part of	Communication between the devices
Background	We need to avoid as much noise as possible
Critical component function	Avoid noise
Positive aspects	The currents flowing in the cables will hopefully not be able to pick up any noise. There will be less work shielding the cables. The cables will be smaller.
Negative aspects	The cables may be able to pick up noise. Not as protected for wear.
Time spent(Hours)	1
Replaces	N/A
Reference	Internal discussion with Sigmund Gudvangen 26.01.2012
Owner and date	S.A 27.01.2012

6.5.2. Shield power and signal cables separately

Part of	Communication between the devices
Background	We need to avoid as much noise as possible
Critical component function	Avoid noise
Positive aspects	The signal cables will not be affected by any current in the power cables.
Negative aspects	We need to separate the cables
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.omega.com/literature/transactions/volume2/analogsignal3.html 25.01.2012
Owner and date	S.A 25.01.2012

6.5.3. Shield power and signal cables together	
Part of	Communication between the devices
Background	We need to avoid as much noise as possible
Critical component function	Avoid noise
Positive aspects	Hopefully, the current in the power cables will not be high enough to affect the signal cables noticeably. Less work than shielding the power and signal cables separately
Negative aspects	The Current that goes through the power cable might interfere with the signals
Time spent(Hours)	1
Replaces	N/A
Reference	N/A
Owner and date	S.A 25.01.2012

6.6. Input protection for microcontroller

6.6.1. Current resistor and Metal Oxide Varistor	
Part of	Every input from both MCC and SC cards.
Background	We need to protect our circuit against the horrible outside world from voltage surges. We found one simple solution with a current limiting resistor and an 5.5 volt MOV(metal oxide varistor) this circuit will protect against 8KV “zapps” without affecting the operation
Critical component function	The components need to react fast enough to protect the microcontroller from voltage and current surges.
Positive aspects	Cheap and good protection, CE approved
Negative aspects	
Time spent(Hours)	2
Replaces	N/A
Reference	http://www.opencircuits.com/Input_protection (page modified 26.October 2011)
Owner and date	O.R 20.02.2012

6.6.2. Littelfuse SP724AHT

Part of	Every input from both MCC and SC cards.
Background	We need to protect our circuit against the horrible outside world from voltage surges.
Critical component function	The component needs to react fast enough to protect the microcontroller from voltage and current surges.
Positive aspects	Good protection. You can protect four lines at each unit. Cheap. Does not take a lot of space.
Negative aspects	N/A
Time spent(Hours)	2
Replaces	6.6.1
Reference	http://www.alldatasheet.com/datasheet-pdf/pdf/122751/LITTELFUSE/SP724AHT.html 20.02.2012 http://www.dz863.com/datasheet-81345363-SP724AHT_Tvs-Diode-Arrays-Scr-Diode-Array-For-Esd-And-Transient-Overvoltage-Protection/ 20.02.2012
Owner and date	S.A 20.02.2012

6.6.3. Input protection with R/C filtering

Part of	Every input from both MCC and SC cards.
Background	We need to protect our circuit against the horrible outside world from voltage surges.
Critical component function	The component needs to react fast enough to protect the microcontroller from voltage and current surges.
Positive aspects	Adding resistors and capacitors will provide some protection. The capacitor resists change in the volt across it, and the resistor will limit the current
Negative aspects	N/A
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.w9xt.com/page_microdesign_pt10_input_protection.html 20.02.2012
Owner and date	S.A 20.02.2012

6.7. Decoupling capacitor

6.7.1. **0.1uF capacitor**	
Part of	MCC & SC
Background	We need to decouple our logic IC's to minimize high currents in a large loop on the PCB to lower EMI
Critical component function	The component helps us eliminate EMI by providing enough power for the IC it supports so we don't get large currents in a big loop on the PCB-board, this gives EMI and voltage drops.
Positive aspects	
Negative aspects	
Time spent(Hours)	2
Replaces	NA
Reference	http://www.hottconsultants.com/techtips/decoupling.html Last read 20.02.2012 made by Henry Ott Consultants
Owner and date	O.R 20.02.2012

6.8. Component package standard

6.8.1. **Surface mount components**	
Part of	MCC & SC
Background	We are making two different PCB-cards for our project which needs to have components soldered to it, we discuss the pros and cons of Surface Mount Devices.
Critical component function	
Positive aspects	Smaller footprints and better EMI specifications
Negative aspects	SMD do not cope high vibration environments
Time spent(Hours)	2
Replaces	NA
Reference	
Owner and date	O.R 22.02.2012

6.8.2. Through hole type

Part of	MCC & SC
Background	We are making two different PCB-cards for our project which needs to have components soldered to it, we discuss the pros and cons of Through Hole devices
Critical component function	
Positive aspects	They are easy to solder, more cost efficient in small and they also cope better with vibration environments and high G-forces which is the main reason we use through hole components
Negative aspects	Takes up a bigger area of the board, and has a bit disadvantage with EMI since it has longer leads which will give some more capacitance and inductance.
Time spent(Hours)	2
Replaces	Surface mount components
Reference	
Owner and date	O.R 22.02.2012

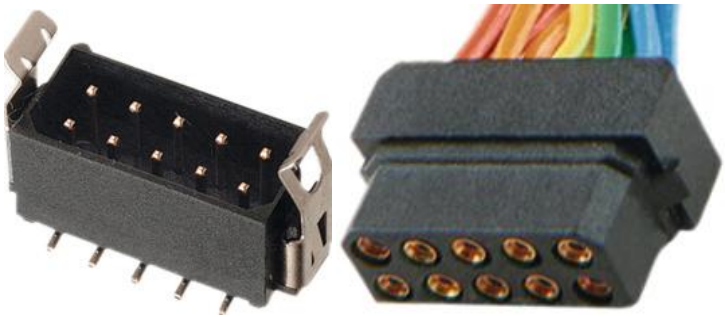
6.9. Joystick

6.9.1. Using an inductive sensor in the joystick

Part of	Joystick
Background	We need to have a sensor who registers movement in the joystick
Critical component function	Works as a sensor, and sends a simple analog signal to the MCC
Positive aspects	Very reliable. Not affected by vibrations, harsh environments, lack of lubricant. Has not got a limited lifespan. Very useable in aviation and other vehicals. Can be connected and directly replaced in a circuit constructed for potentiometers.
Negative aspects	More expensive than a potentiometer.
Time spent(Hours)	2
Replaces	Using potentiometer as a sensor in the joystick
Reference	http://en.wikipedia.org/wiki/Inductive_sensor 06.02.2012 http://www.controlengeurope.com/article/38145/Potentiometers-suffering-because-of-the-failure-of-a-few-in-harsh-environments.aspx 06.02.2012
Owner and date	S.A 06.02.2012

6.9.2. **Using potentiometer as a sensor in the joystick**	
Part of	Joystick
Background	We need to have a sensor who registers movement in the joystick
Critical component function	Works as a sensor, and sends a simple analog signal to the MCC
Positive aspects	Simple, cheap, reliable in right working conditions, well-known
Negative aspects	Unreliable due to vibrations and harsh environments. Mechanical measurement. Has a limited lifespan (500.000 cycles for a good potentiometer). If exposed to vibration, the vibrations count as a cycle, which will reduce the lifespan dramatically– from several years, to days because of mechanical wear. Also attraction of dust, sand and other foreign elements will decrease the lifespan.
Time spent(Hours)	2
Replaces	N/A
Reference	http://www.controlengeurope.com/article/38145/Potentiometers-suffering-because-of-the-failure-of-a-few-in-harsh-environments.aspx 06.02.2012
Owner and date	S.A 06.02.2012

6.10. Connector

6.10.1. **Harwin**	
Part of	MCC and SC
Background	We need to decide which connectors that shall be used on the PCBs to connect de different parts of the system
Critical component function	The connectors must be resistant to vibration. It is important because It is a lot of vibration in the plane and we do not the connectors to disconnect.
Positive aspects	This connectors are resistant to vibration. This component is through hole mounted.
Negative aspects	
Time spent(Hours)	2
Replaces	N/A
Reference	https://www.elfaelektronikk.no/elfa3~no_no/elfa/init.do?item=43-951-26 13.02.2012 https://www.elfaelektronikk.no/elfa3~no_no/elfa/init.do?item=43-959-28&toc=19792 13.02.2012 
Owner and date	R.L 13.02.2012

6.10.2. **BLF 5.08/../90**	
Part of	MCC
Background	We need to find a suitable connector for the joystick on the MCC
Critical component function	Transmit analogue data from the joystick to the MCC without losing data
Positive aspects	It is robust and without screws.
Negative aspects	It is not suitable for shielded cables
Time spent(Hours)	3
Replaces	N/A
Reference	http://weidmuller.com/system/files/webfm/downloads/pdfs/literature/1250030000_CAT2_BLF.pdf 25.01.2012
Owner and date	A.G & R.L / 25.01.2012

6.10.3. **4 bit Ethernet cable**	
Part of	MCC/SC
Background	What kind of connectors shall be used for serial communication
Critical component function	We need a cable that are resistant to vibration
Positive aspects	It has a lock function which helps it not to disconnect because of vibration
Negative aspects	The lock function is not very safety
Time spent(Hours)	1
Replaces	8.2
Reference	N/A
Owner and date	R.L 17.01.2012

6.10.4. **BLF 5.08HC/03/90 SN BK BX**	
Part of	MCC/SC
Background	What kind of connectors shall be used for serial communication
Critical component function	We need a cable that are resistant to vibration
Positive aspects	It is spring loaded, which is the most important property
Negative aspects	N/A
Time spent(Hours)	2
Replaces	N/A
Reference	http://weidmuller.com/system/files/webfm/downloads/pdfs/literature/1250030000_CAT2_BLF.pdf 17.01.2012
Owner and date	A.G & R.L 17.01.2012

6.10.5. We decided to not spend more time on this issue, and used standard DuPont Connector, this has 0.1” spacing So these can be replaced by others.

6.11. Power connector

6.11.1. **AMPINNERGY**	
Part of	MCC
Background	The other connectors we use cannot carry enough current for our stepper motors. So we need a connector that can carry enough current >10amp. We found a connector which can carry up to 35 amperes. Ampinnergy556879-2 and Ampinnergy556882-2, Connector&Contact
Critical component function	The connector needs to carry at least ten amperes and needs to be spring loaded.
Positive aspects	High current rating and heavy duty construction
Negative aspects	Big footprint
Time spent(Hours)	3
Replaces	6.10.1
Reference	Product-link Last read 08.03.2012
Owner and date	O.R 08.03.2012

6.11.2. **LMZFL 5/2/135 3.5SW**		
Part of	MCC	
Background	The other connectors we use cannot carry enough current for our stepper motors. So we need a connector that can carry enough current >10amp	
Critical component function	The connector needs to carry at least ten amperes and needs to be spring loaded.	
Positive aspects	This connector can handle currents up to 24A and cable thickness up to 2.5mm^2 The connector is small; W/L/H 13mm/14.5mm/16.7mm	
Negative aspects	The connection point is 45˚ (135˚) with the circuit board	
Time spent(Hours)	2	
Replaces	6.11.1	
Reference	1. http://search.digikey.com/no/en/products/1811510000/1811510000-ND/2638883 2. http://media.digikey.com/PDF/Data%20Sheets/Weidmuller%20PDFs/1811510000.pdf 3. http://catalog.weidmueller.com/catalog/Start.do?localeId=en&ObjectID=1811510000	
Owner and date	AG	08.03.2012

6.11.3. **ED2237**		
Part of	MCC and SC	
Background	The other connectors we use cannot carry enough current for our stepper motors. So we need a connector that can carry enough current >10amp	
Critical component function	The connector needs to carry at least ten amperes and needs to be spring loaded.	
Positive aspects	This connector can handle currents up to 16A and cable thickness up to $2mm^2$	
Negative aspects	The connection point is 45˚ (135˚) with the circuit board	
Time spent(Hours)	2	
Replaces	6.11.1	
Reference	4. http://media.digikey.com/pdf/Data%20Sheets/On%20Shore%20PDFs/ED3000.pdf	
Owner and date	O.R	16.05.2012

6.12. Temperature sensor

The temperature sensor is to be used to monitor the temperature around the circuit board to prevent it from getting to warm and also give a notice if the temperature is too low.

Table 5: Hardware research template

6.12.1. **LM 335A Analog temperature sensor**	
Part of	MCC and SC
Description	- Temp limits: -40 to +100C - Directly calibrated in Kelvin - Output: 10mV/K Linear output - Less than 1ohm dynamic impedance - Operates from 400microA to 5mA
Critical component function	Notifying the user that the temperature does not exceed critical limits.
Positive aspects	Low cost
Negative aspects	Needs calibration
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.sparkfun.com/products/9438
Owner and date	K.M 02.02

6.12.2. **Thermistor 10K**

Part of	MCC and SC
Description	- Temp limits: -40 to +125C -
Critical component function	Notifying the user that the temperature does not exceed critical limits.
Positive aspects	Low cost
Negative aspects	Inaccurate
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.sparkfun.com/products/9438
Owner and date	K.M 02.02

6.12.3. **TMP 36 Analog temperature sensor**

Part of	MCC and SC
Description	Notifying the user that the temperature does not exceed critical limits.
Critical component function	- Power supply range 2.7-5.5V - Temp limits: -40 to +125C (+/-2C) - Output: 10mV/C Linear output
Positive aspects	No calibration needed, low cost
Negative aspects	Inaccurate
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.sparkfun.com/products/10988
Owner and date	K.M 02.02

6.12.4. **DS18B20 One Wire digital temperature sensor**

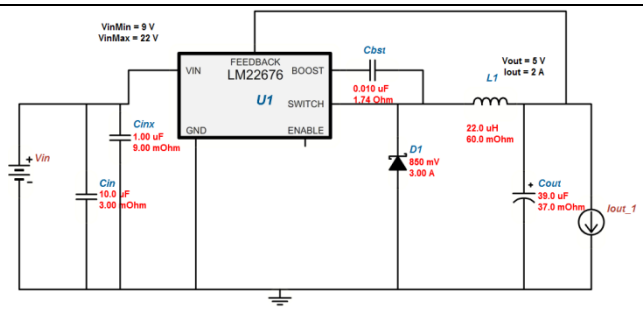
Part of	MCC and SC
Description	- Each sensor has a unique 64bit address so it can be connected in a 1-wire network. - Temp limits: -55 to +125C (+/-0.5C) - Power supply range 3-5.5V - Resolution is user selectable from 9-12 bits - Converts temperature to 12-bit digital word in 750ms
Critical component function	Notifying the user that the temperature does not exceed critical limits.
Positive aspects	No calibration needed
Negative aspects	A bit costy. Around 4USD a piece, more complicated than the analogue ones.
Time spent(Hours)	1
Replaces	N/A
Reference	http://www.sparkfun.com/products/245
Owner and date	K.M 02.02

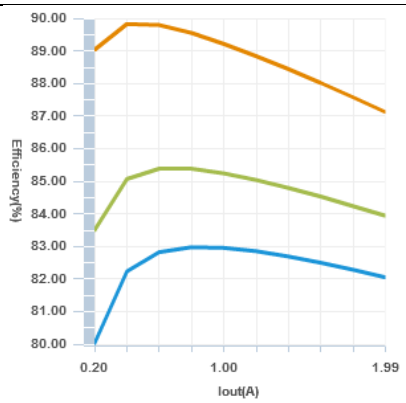
6.13. Power supply

6.13.1. LM2596

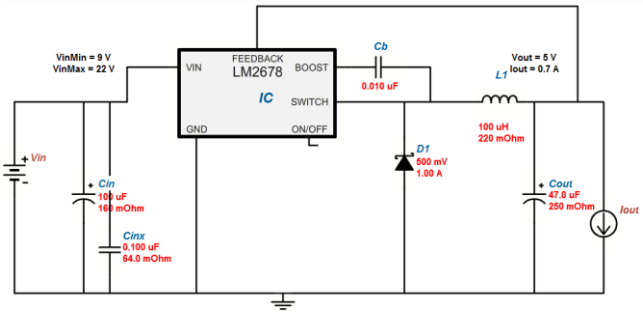
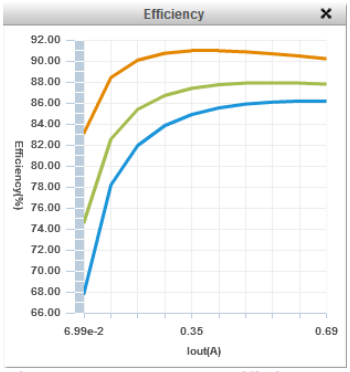
Part of	Power supply
Background	We had a discussion with our external supervisor and we agreed that we would be Better off with buying a complete PSU-circuit rather that make our own from scratch. We therefore found one option that is really similar to the other options.
Critical component function	We need an efficient power supply which also has a stable output voltage.
Positive aspects	Complete PSU for a very low price and easy implementation! Lower ripple that the other PSUs (5mV)
Negative aspects	Less control over the PCB-layout will need more EMI research.
Time spent(Hours)	2
Replaces	6.13.2
Reference	http://www.ti.com/general/docs/lit/getliterature.tsp?genericPartNumber=lm2596&fileType=pdf (LM2596-data sheet) http://www.buyincoins.com/details/lm2596-step-down-adjustable-dc-dc-power-supply-module-new-product-9004.html (whole module)
Owner and date	O.R 09.02.2012

6.13.2. LM22676QMRE-5.0

Part of	**Power supply**
Background	We look into other options that option 6.4.1
Critical component function	 Figure 1: Circuit schematic

	 **Figure 2: Efficiency**
Positive aspects	Even lower Part cost than option 1, and the same part count(6). The Vout p-p is better that option 1(10mV). The max current is 3A which is way more than we expect the system to use.
Negative aspects	Lower efficiency that option 1, but it is still >80% which is great! But this is still a switching power supply which can be a source for EMI
Time spent(Hours)	3
Replaces	**6.13.3**
Reference	Schematics and graphs: http://www.national.com/appinfo/webench/scripts/c.cgi?ID=1234543_NSjd8dZZDb4C2_power_111154
Owner and date	O.R 19.1.2012

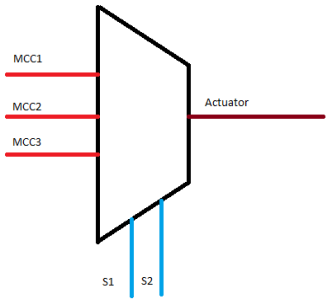
6.13.3. **LM2678S-5.0**

Part of	Power supply
Background	We need a power supply that can supply our system with 5v from the 12 volts that is the supply we can get power from. We need a PSU that can give us a stable output voltage of 5 volts and at least 2 amperes of current. We are focusing on switching regulators since they are a lot more efficient than linear converter that will make a lot of heat @ 2Amps (2A*(12-5)V=14W) the switching regulator can achieve a efficiency higher that 90% in optimal conditions that reduces the heat a lot!
Critical component function	This Converter has an efficiency of 86 percent when Iout is 0.7Amps  Figure 3:Circuit Schematic[1]  Figure 4:Converter efficiency
Positive aspects	Low external part count (6) Low part costs(4.26$)Vout p-p: 40mV
Negative aspects	May be abit overkill for our project, we don't need 5 Amps of current. Also Switching power supply can be a source for EMI
Time spent(Hours)	3
Replaces	None
Reference	Schematics and graph: [1]http://www.national.com/appinfo/webench/scripts/SD2.cgi?ID=111162::power::riiserhob@gmail.com
Owner and date	O.R 18.1.2012

6.13.4. **LM 7805**

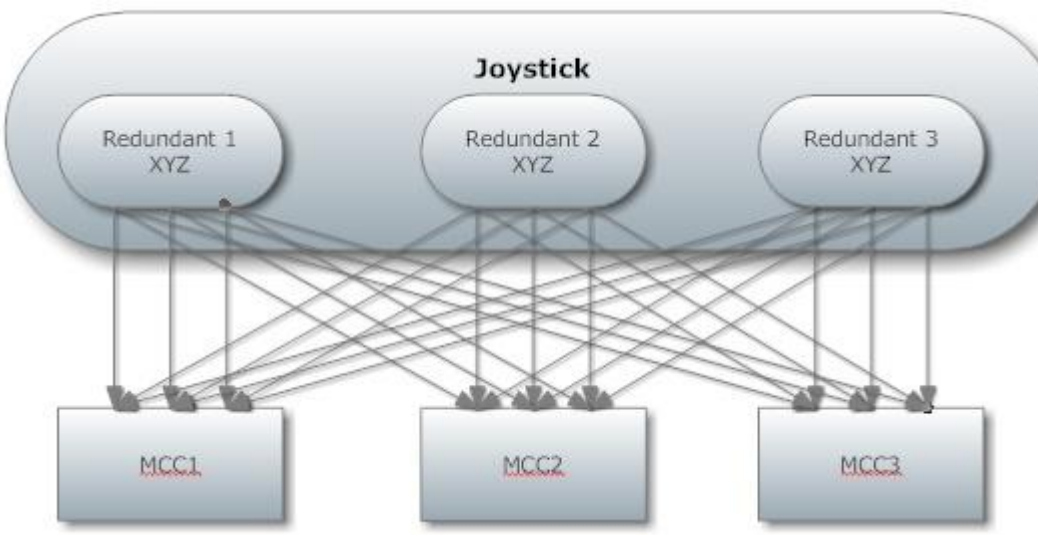
Part of	Logic supply
Description	Will regulate the power from 13.8 V down to 5V needed for the logic circuits.
Critical component function	- Output current up to 1.5A - Internal thermal overload protection - Internal short circuit current limiting - Min input voltage 7V Max input voltage 25V - Output voltage 5V (+/-0.2V) - Operating temperature 0-125C - Output noise voltage 40microV
Positive aspects	Cheap, high ripple noise rejection, less components than the switching regulators and they are through hole.
Negative aspects	Produces more heat, but for the current consumption on our board, it' won't be a problem.
Time spent(Hours)	1
Replaces	6.13.1
Reference	http://www.sparkfun.com/datasheets/Components/LM7805.pdf 02.02.2012
Owner and date	O.R 20.03.2012

6.14. Choosing MCC Signal

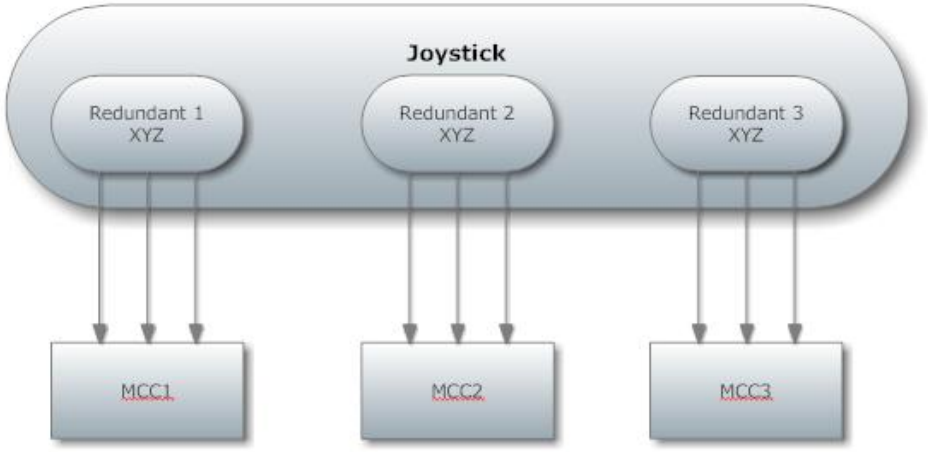
6.14.1. **Multiplexing**	
Part of	MCC
Background	We have multiple MCC and an SC that has to choose which of the MCCs that will control the stepper motors on the control surfaces.  Figure 5: Actuator signal routing
Critical component function	We need to make sure that only one of the signals can make it to the stepper driver without any interference from the other signals as they still are available for use.
Positive aspects	This is an easy controllable system which isolates every other signals efficiently
Negative aspects	This is a critical part of the system that cannot fail, so if the power supply to this circuit fails the system is useless. We also need one multiplexer per signal to the stepper controller which can take a lot of space on the PCB
Time spent(Hours)	3
Replaces	N/A
Reference	http://www.electronics-tutorials.ws/combination/comb_2.html
Owner and date	O.R 26.1.2012

6.14.2. **Enable each MCC card controller**	
Part of	MCC
Background	We have multiple MCCs that can control the stepper motors.
Critical component function	We have to find a way to control that only one MCC can control the stepper motors at any given time. This option is that we can implement five stepper controllers on each MCC and use the enable pins on these controllers to choose which of the MCCs stats in charge of the stepper motors.
Positive aspects	This removes the single failure aspect of the other option.
Negative aspects	The MCCs gets more expensive since it needs more HW
Time spent(Hours)	4
Replaces	6.14.1
Reference	Discussion with external supervisor
Owner and date	O.R 09.02.2012

6.15. Redundancy

6.15.1. **Triple redundancy to MCC**	
Part of	MCC
Background	We use a dual/triple redundancy setup on the joystick and MCC and we have some different options on how we connect all the redundant axis to the MCC's One option is to have all the redundant axis into all of the MCC's which will give every MCC the option to find the best signal source and use this. 
Critical component function	These signals will give the MCC the user a set point and needs to be isolated so we still have single failure tolerance. The setup we try here will need extra circuitry for this to function
Positive aspects	The MCCs can see which of the joystick reading that is the best, and working properly. This gives extra safety if made properly.
Negative aspects	The risk with this is that one MCC has the access to all the joystick signals, which in a worst case scenario can interfere with all the signals and corrupt them e.g. if one of the MCCs get destroyed due to mechanical stress. This can also happen in software if the analog read pin is set high or low by mistake. This system is actually not redundant by definition
Time spent(Hours)	2
Replaces	N/A
Reference	N/A
Owner and date	O.R 27.1.2012

6.15.2. **Parallel redundancy**

Part of	MCC
Background	We use a dual/triple redundancy setup on the joystick and MCC and we have some different options on how we connect all the redundant axis to the MCC's This option makes three parallel systems which is isolated like the figure below 
Critical component function	These signals will give the MCC the user set point from the joystick
Positive aspects	We have three isolated and parallel circuits that eliminate single failure.
Negative aspects	If one axis on each redundant potentiometer fails e.g.(x-axis on red.1, y-axis on red. On red. 2 & z-axis on red. 3)
Time spent(Hours)	5
Replaces	Triple redundancy to MCC
Reference	6.15.1
Owner and date	O.R 27.1.2011

6.16. Microcontroller

The Microcontroller of choice is the PIC18F8520. Our contractor wanted us to use this MCU both for the SC and the MCC; therefore we have not done much research on other types of MCU's

6.16.1. **PIC18F8520**	
Part of	MCC & SC
Background	We will need to decide on a MCU for the SC and the MCC cards
Critical component function	- Pin Count: 80 - Program memory: 32KB - CPU speed: 10MIPS - RAM: 2048 bytes - Data EEPROM: 1024 bytes - Digital Communication Peripherals: 2-A/E/USART, 1-MSSP(SPI/I2C) - Capture/Compare/PWM Peripherals: 5CCP - Timers: 2 x 8-bit, 3 x 16-bit - ADC: 16-channels, 10-bit - Comparators: 2 - Temperature range: -40 to 125 ˚C - Operating Voltage Range: 2V to 5.5V
Positive aspects	A lot of extra I/O's, well known manufacturer
Negative aspects	N/A
Time spent(Hours)	1
Replaces	N/A
Reference	[1]
Owner and date	A.G 18.01.2012

6.16.2. **LPC1768**	
Part of	SC
Background	We needed a more powerful microcontroller for the SC card
Critical component function	"*The LPC1768 microcontroller has 512KB of internal flash and 64KB RAM. Ethernet MAC, USB Device/Host/OTG interface, 8-channel general purpose DMA controller, 4 UARTs, 2 CAN channels, 2 SSP controllers, SPI interface, 3 I2C-bus interfaces, 2-input plus 2-output I2S-bus interface, 8-channel 12-bit ADC, 10-bit DAC, motor control PWM, Quadrature Encoder interface, 4 general purpose timers, 6-output general purpose PWM, ultra-low power Real-Time Clock (RTC)*" http://www.sparkfun.com/products/9931
Positive aspects	If this is used we can lower our part count and end up with a lot more power supervisor which has a USB-interface and four UARTS, And we are going to need all of them! It is important to understand that this only applies to the SC and NOT the MCC
Negative aspects	A lot of configuration on the software side
Time spent(Hours)	1
Replaces	PIC18F8520
Reference	
Owner and date	O.R 03.05.2012

6.17. Stepper controller

Stepper motor controller is used to control the current going to the motor. This controller needs to be used as a piggyback module on our MCC cards.

6.17.1. Big Easy driver

Part of	MCC
Description	Control of the stepper motor
Critical component function	- Max current 2A per coil - Max motor voltage 35V - On board voltage regulator - Five different step resolutions
Positive aspects	Built in current limiter, open-source
Negative aspects	Big size, high cost
Time spent(Hours)	2
Replaces	N/A
Reference	http://www.sparkfun.com/products/10735
Owner and date	K.M & A.G 02.02

6.17.2. A4899 Stepper motor driver

Part of	MCC
Description	Control of the stepper motor
Critical component function	- Power supply logic control 3-5.5V - Max current 2A per coil - Motor voltage 8-35V - Five different step resolutions
Positive aspects	Built in current limiter, high temperature shut down, under voltage lockout, small size, low cost
Negative aspects	N/A
Time spent(Hours)	2
Replaces	Big Easy driver
Reference	http://www.pololu.com/catalog/product/1182
Owner and date	K.M & AG 02.02

6.18. Stepper motor

The reason for using a stepper motor instead of an actuator is simply because it was a wish from Knut Brodreskift. Also the shaft on the stepper motor will be easy to swivel when the stepper motor is off power. This is a positive aspect when it comes to safety issues. An actuator will in most cases stay in the last position it had if it lose power, and this could cause serious problems when the aircraft is airborne.
This is the motor which will control the control surfaces.

6.18.1. Sanyo Denki 2-phase, type: 103H5208-10U41, NEMA 17

Part of	Airplane body
Description	Will control the wings of the airplane. This is a unipolar stepper motor.
Critical component function	- 1.8 step per resolution - Hold torque: 4.25 kg/cm - 10.6 ohm per phase in bipolar setup - Weight 0.29 kg - 17.2 mH inductance per phase in bipolar setup - Recommended power supply 24VDC, min 1.7A in bipolar setup - Recommended controller reference power 1.4V, 0.85A per phase in bipolar setup
Positive aspects	Cheap, ability to be controlled as a bipolar stepper motor which yields higher torque. Lightweight
Negative aspects	N/A
Time spent(Hours)	3
Replaces	N/A
Reference	http://www.ebay.com/itm/Sanyo-2-Ph-Step-Stepper-Motors-CNC-Router-103H5208-10U41-Nema-17-Frame-Hobby-NEW-/300657930592?pt=BI_Robotics&hash=item46009bf160#ht_6992wt_1270
Owner and date	K.M 02.02

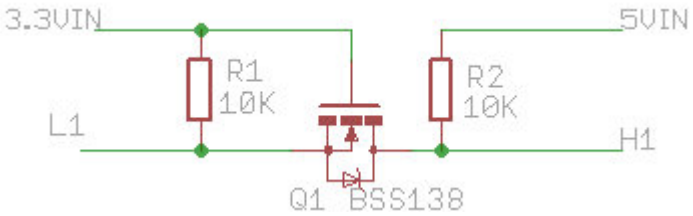
6.19. Inertial Measuring

6.19.1. 9 degrees of freedom(gyro , accelerometer & magnetometer)

Part of	SC
Background	We need to measure the position of the airplane in order to implement autopilot and to check if the pilot makes any critical errors. We have found a lot of ways to do this but we need atleast two sensors: A gyroscope and a accelerometer. The gyroscope measures the angular velocity and the accelerometer measures the forces the plane is exposed to. These two sensors can be combined in software to get a great result.
Critical component function	They need to give accurate readings and be easy and accessible and have a fast response time. The Sparkfun 9 degrees of freedom uses an i^2c interface which has a very fast data rate and conversion time compared to analog outputs.
Positive aspects	I^2c bus, very small footprint and it has everything we need to measure the planes angle in every direction.
Negative aspects	High cost and it communicates on a 3.3 volt bus, when the PIC is 5v, this requires a level converter.
Time spent(Hours)	3

Replaces	NA
Reference	http://www.sparkfun.com/products/10183 Last read 5.3.2012
Owner and date	O.R. 5.03.2012

6.19.2. Level conversion for i²c-bus

Part of	Sc (i²c-bus)
Background	The IMC and barometer communicates over a 3.3v bus, and the pic has a 5v interface.
Critical component function	This needs to be converted in both directions in order to function properly. Both from 5v->3.3v and from 3.3v→5v. we can use a FET transistor to do this in this way:  Figure 6: Logic translation
Positive aspects	We only need three basic parts to do the translation bidirectional. And we need two of these setups in order to translate both SDA and SCL lines.
Negative aspects	it is six parts we would like to not have in the board.
Time spent(Hours)	4
Replaces	No translation
Reference	http://www.rocketnumbernine.com/2009/04/10/5v-33v-bidirectional-level-converter Last Read: 05.03.2012
Owner and date	O.R 05.03.2012

6.19.3. This is not needed after the change of Microcontroller which operates at 3.3V

6.20. Linear voltage regulator

6.20.1. LM 317

Part of	Joystick power supply
Description	Will regulate the power from 13.8 V down to 5V needed for the analogue conversion for the joystick.
Critical component function	- Output current greater than 1.5A - Internal thermal overload protection - Internal short circuit current limiting - Output voltage 1.25 to 37V - Operating temperature 0-125C - Output noise voltage 0.003V
Positive aspects	Cheap
Negative aspects	
Time spent(Hours)	1

Replaces	
Reference	http://www.sparkfun.com/datasheets/Components/LM317.pdf 02.02.2012
Owner and date	K.M. 02.02.2012

6.20.2. **LM 7805**

Part of	Joystick power supply
Description	Will regulate the power from 13.8 V down to 5V needed for the analog conversion for the joystick.
Critical component function	- Output current up to 1.5A - Internal thermal overload protection - Internal short circuit current limiting - Min input voltage 7V Max input voltage 25V - Output voltage 5V (+/-0.2V) - Operating temperature 0-125C - Output noise voltage 40microV
Positive aspects	Cheap, high ripple noise rejection
Negative aspects	
Time spent(Hours)	1
Replaces	
Reference	http://www.sparkfun.com/datasheets/Components/LM7805.pdf 02.02.2012
Owner and date	K.M. 02.02.2012

6.21. Current regulators

6.21.1. **Current regulator with 5 output on 2A**

Part of	MCC
Background	We need a regulator to control the current to each stepper motor
Critical component function	The regulator should be able to give maximum 2 A to each stepper motor
Positive aspects	This regulator will give maximum 2 A to each stepper motor. And there is no risk that one motor use more current, and that it will affect on the other stepper motors.
Risk Profile	N/A
Time spent(Hours)	1
Replaces	6.21.2
Reference	N/A
Owner and date	R.L 01.02.2012

6.21.2. **Current regulator with one output on 10A**	
Part of	MCC
Background	We need a regulator to control the current to each stepper motor
Critical component function	The regulator should be able to give maximum 2 A to each stepper motor
Positive aspects	It will regulate the total current to the 5 stepper motors to maximum 10 A
Risk Profile	There is a possibility that one stepper motor will use more than 2 A which will cause in to little current to the other motors.
Time spent(Hours)	1
Replaces	N/A
Reference	N/A
Owner and date	R.L 01.02.2012

6.21.3. This is not needed because of the current regulators on the stepper controllers

6.22. HMI LEDS

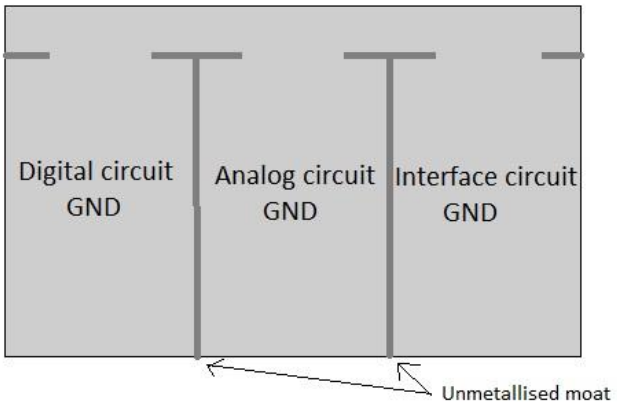
6.22.1. **Status LEDs HMI**	
Part of	HMI
Background	We need to have a bi-color LED who indicates the statuses on the MCCs.
Critical component function	Shows status on the MCC We have done some calculations on this. The multicolor LEDS have different volt drops which require different resistors. The red LED only needs 3mA to get a bright light. The green one needs 15 mA to get a bright light. So the calculated resistors are 1k Ω for the red, and 200 Ω on the green.
Positive aspects	Cheap safety and simple overview
Negative aspects	N/A
Time spent(Hours)	2
Replaces	N/A
Reference	N/A
Owner and date	S.A & O.R 07.03.2012

6.22.2. **Status LEDs HMI**	
Part of	HMI
Background	We cannot use Bi-color LEDs for our HMI since people with color-blindness can't tell the difference if the LED is green or red.
Critical component function	Shows status on the MCC We have done some calculations on this. The LEDS have different volt drops which require different resistors. The red LED only needs 3mA to get a bright light. The green one needs 15 mA to get a bright light. So the calculated resistors are 1k Ω for the red, and 200 Ω on the green.
Positive aspects	Cheap safety and simple overview
Negative aspects	N/A
Time spent(Hours)	1
Replaces	Bicolor LEDs
Reference	N/A
Owner and date	O.R 03.05.2012

6.23. Ground plane on PCB

6.23.1. **Separate ground planes w/ one small connection between analog and digital ground plane.**	
Part of	Ground plane on the PCB's
Background	We need to avoid as much noise we can. And try to reduce the EMC on the card.
Critical component function	If we separate the analog ground plane from the digital ground plane with a small connection, we will be able to maintain the same potential and reference in both domains. The small connection will not transfer noise and other unbalances between the domains.
Positive aspects	The analog part of the circuit will not record noise from the digital part and the switching regulator.
Negative aspects	N/A
Time spent(Hours)	3
Replaces	N/A
Reference	http://www.ce-mag.com/ce-mag.com/archive/01/03/0103CE_028.html 07.03.2012 http://www.analog.com/library/analogDialogue/archives/39-09/layout.html 07.03.2012
Owner and date	S.A 07.03.2012

6.23.2. **Moated ground plane**	
Part of	Ground plane on the PCB's
Background	We need to avoid as much noise we can. And try to reduce the EMC on the card.
Critical component function	If we create a moated ground plane, we will reduce the coupling between circuits by basic physical separation. We will be able to maintain the same potential and reference in both domains. Noise voltage and power surge will be

	prevented since the grounds to the other circuits will be so far away in distance because of the gap between the circuits. 
Positive aspects	The analog part of the circuit will not record noise from the digital part and the switching regulator.
Negative aspects	N/A
Time spent(Hours)	2
Replaces	N/A
Reference	"EMC at component and PCB level" By Martin O'Hara 1998. Newnes. Page 124.
Owner and date	S.A 08.03.2012

6.23.3. **Solid Ground Plane**

Part of	Ground plane on the PCB's
Background	We need to avoid as much noise we can. And try to reduce the EMC on the card.
Critical component function	The simplest and best solution we've came up with is just to have a solid plane.
Positive aspects	Simple and great solution
Negative aspects	N/A
Time spent(Hours)	2
Replaces	Moated Ground Plane
Reference	
Owner and date	S.A 08.03.2012

6.24. Communication with external screen (android tablet)

6.24.1. **Vinculum II**	
Part of	SC
Background	We need a UART to USB converter in order to communicate with the advanced user interface(where the pilot can edit parameters and autopilot setpoints) We found the Vinculum Chip from FTDI. Which is can be interfaced with android
Critical component function	Communicate with Android device
Positive aspects	Powerful Chip, this may help the PIC with heavy computations when the system is further developed.
Negative aspects	Adds more complex components to the SC board.
Time spent(Hours)	5
Replaces	UART communication
Reference	http://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_Vinculum-II.pdf (how to access android accessory mode) Last Read 20.03.2012 http://apple.clickandbuild.com/cnb/shop/ftdichip?op=catalogue-products-null&prodCategoryID=117&title=V2DIP2 (braked out chip with needed interface) Last Read 20.03.2012
Owner and date	O.R 20.03.2012

6.24.2. This is not needed after the change of Microcontroller, which has internal USB.

7. REVISIONS

Responsible person for this document, procedure or template

Rev	Description	Date	Name
0.1	Made templates, wrote introduction	13.01.2012	S.A
0.2	Filled inn abbreviation list, and made 6.2 microcontroller + some cosmetic and practical changes to the tables	18.01.2012	A.G
0.3	Gathered together all the finished hardware researches we have done till 01.02.2012	02.02.2012	S.A
0.4	Added Linear regulator research	08.02.2012	K.M
0.5	Cleaned up the document and added PSU research	09.02.2012	O.R
0.6	Gathered together finished hardware researches we have done from 01.02.2012 till 17.02.2012	17.02.2012	S.A
0.7	Made: 6.11.1 6.11.2 6.19.2	08.03.2012	AG / O.R
0.8	Made : 6.13.4 and 6.24.1	20.03.2012	O.R
0.9	Made updates after change of microcontroller	03.05.2012	O.R
0.10	Made more updates on outdated tables. Finished documents	16.05.2012	O.R
1	Made last revision	22.05.2012	O.R

Table 6: Revisions

SOFTWARE DESCRIPTION

Bachelor Project

Compact Fly-By-Wire System

Version	1.0
Category	Released
Issue Date	29.05.2012
Made by	A.G
Checked by	K.M
Approved by	T.A

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1. PURPOSE

The purpose of this document is to give a general overview of the software part of the project. This is done with class- and activity diagrams for both the SC and MCC. The source code and a more detailed description of the software will be on the CD.

2. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser

3. DEFINITIONS

Name	Description
MCC	Main Controller Card
SC	Supervision Card
MCU	Microcontroller Unit
MIPS	Million Instructions Per Second
EEPROM	Electrically Erasable Programmable Read-Only Memory
USART	Universal Synchronous/ Asynchronous Receiver/Transmitter
PWM	Pulse-Width Modulation
CCP	Capture/Compare/PWM
SPOF	Single Point Of Failure

3. RESEARCH

3.1. Code language

When writing code for the Main Controller Cards we had the option to write code in C or Basic. We have chosen C. The main reason is because it is more used and support is easier to get.

3.2. State failure research

We have to consider how the system will respond to a failure to the critical system functions (MCC and the SC) Therefore we have done some state failure research;
Explanations to the Tables:

- Green V means that the card is working properly.
- Red X means that the card is not working properly or has broken down.
- The RESULT describes what the system does in each of the different cases.
  - MCC1: MCC1 will be assigned.
  - MCC2: MCC2 will be assigned.
  - MCC3: MCC3 will be assigned.
  - HMI: The pilot has to intervene and assign an MCC.
  - SYSTEM FAIL: The system has failed, and the pilot may use the trim tabs to control the control surfaces or pull the reserve parachute.

3.3. Single failure on SC

Table 1: describes the result if the MCC's and the SC fails.
In this example the SC is a Single Point Of Failure, which means that if the SC fails to work, the SC will not send commands to the MCC's. When none of the MCC's receive an enable signal from the SC, the MCC's do not know what to, and the pilot have to intervene and use the Analog HMI to assign a operating MCC. If this were to happen during critical operations such as takeoff, landing, flying in a lot of air traffic etc. The consequences can be fatal because of the small margins the pilot have for errors. The time it takes for the pilot to understand what is happening and to do something about the situation (assign an MCC) might be time the pilot does not have.

Single failure on SC

EVENT:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SC	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V	X
MCC1	V	V	X	X	V	V	X	X	V	V	X	X	V	V	X	X
MCC2	V	V	V	V	X	X	X	X	V	V	V	V	X	X	X	X
MCC3	V	V	V	V	V	V	V	V	X	X	X	X	X	X	X	X
RESULT	MCC1	HMI	MCC2	HMI	MCC1	HMI	MCC3	HMI	MCC1	HMI	MCC2	HMI	MCC1	HMI	SYSTEM FAIL	SYSTEM FAIL

Table 1: Single failure on SC

To further explain we made a FTA diagram of the problem in **Figure 1**:

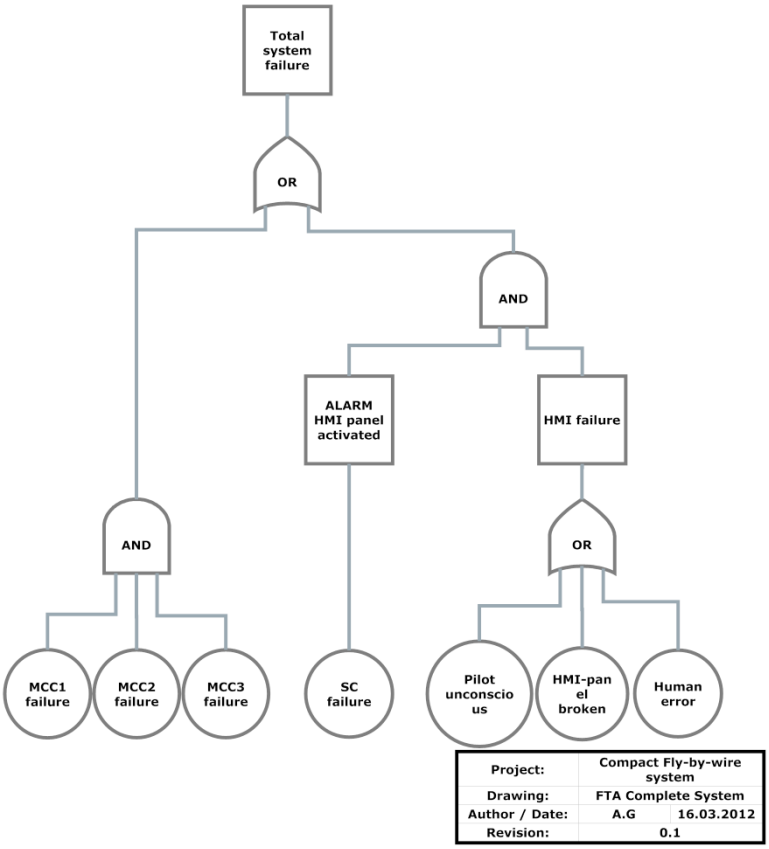

Figure 1: FTA complete system

If the SC fails with this system setup, the system function depends on the pilot's reaction. Because of these safety reasons we want to avoid the full dependency of the HMI-panel as much as possible.

3.4. MCC2 Backup

Description of Table 2:
When SC is working it will send a message to MCC2, telling it that MCC1 or MCC3 is operational. Then if the SC were to break down, the MCC2 will lose the message from the SC and it will assign itself as operational. When MCC1 or MCC3 lose contact with SC they will go in standby mode. This way the system will automatically assign MCC2 as the operational MCC if the SC breaks down. And we will avoid four of the seven events resulting with HMI.

MCC2 is chosen if contact with SC is lost, or SC has failed																
EVENT:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SC	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V	X
MCC1	V	V	X	X	V	V	X	X	V	V	X	X	V	V	X	X
MCC2	V	V	V	V	X	X	X	X	V	V	V	V	X	X	X	X
MCC3	V	V	V	V	V	V	V	V	X	X	X	X	X	X	X	X
RESULT	MCC1	MCC2	MCC2	MCC2	MCC1	HMI	MCC3	HMI	MCC1	MCC2	MCC2	MCC2	MCC1	HMI	SYSTEM FAIL	SYSTEM FAIL

Table 2: MCC2 Backup

To further explain the advantages of this function you can see from **Figure 2**. That the MTBF will be higher and the full dependency of the HMI-panel and pilot reaction is less likely to happen, because both MCC2 and SC will have to fail at the same time.

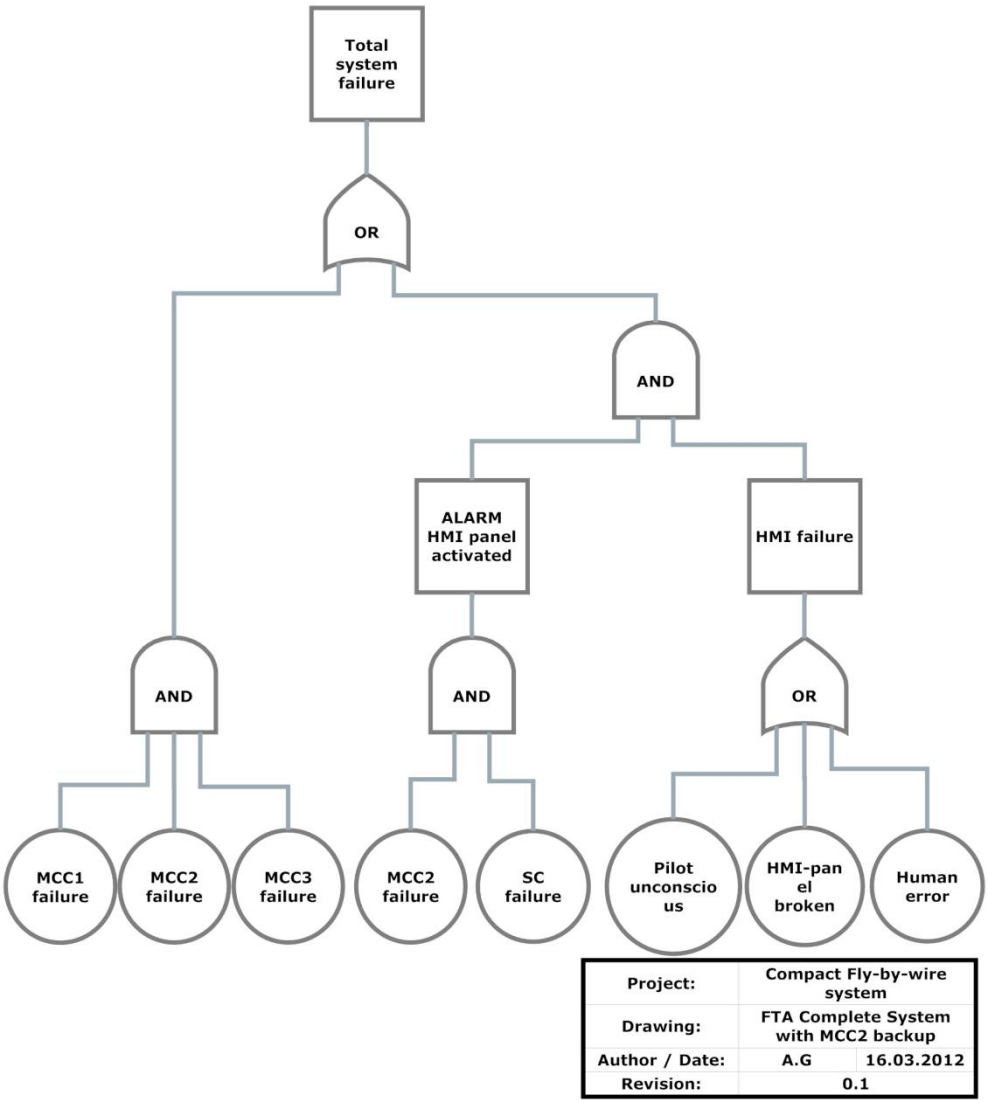

Figure 2: FTA Complete System with MCC2 backup

3.5. Simulator

To our system we have used a freeware simulator called Flightgear to illustrate the system. We have tried a lot of different ways to communicate with the simulator and these options are described here. All ways are using serial communication and a Arduino Mega microcontroller, but with different protocols.

3.5.1. Generic Protocol

With this protocol it is possible to send input to Flightgear and receive data from Flightgear, but it is not possible to do both at the same time. This is the reason that we tried the telnet protocol, to see if it is possible to get feedback at the same time as we send inputs. For more technical specifications about this protocol and our solution, see the software description

document. The arduino will receive serial data from the system, scale it in the format the flightgear needs, and send it out as a new serial line to flightgear. It is required to make a XML file to make flightgear understanding which serial input that shall be send to which parameter in flightgear. For more info about the code and other technical information for this protocol, see the Software description document.

3.5.2. Telnet Protocol

This protocol is a bit more flexible than Generic. With this protocol we send unscaled data to the PC from the Arduino. The Arduino is simply just used to send data. The unscaled data are we modulating in a Python script at the PC. In the Python script we include the telnet protocol, so this script can talk directly to Flightgear without a XML file. In this protocol we got only feedback from the parameters that we send in to the simulator, which it useless in this case.

A part of the code developed for Python script are sown under. We do not make a complete code for this solution because it was replaced by the generic protocol.

```
while(1):

        s = arduino.read(3)

        if(s == "POT"):
                s = arduino.read(1)

                if(s == "E"):
                        elevator = int(arduino.read(5))
                        elevatorOut = scale*elevator;
                        elevatorOut= elevatorOut -1

                        print "elevator set: %f" % (elevatorOut)
                        fg.write("set /controls/engines/engine/throttle %f\r\n" % (elevatorOut))

                if(s == "A"):
                        aileron = int(arduino.read(5))
                        aileronOut = scale*aileron
                        aileronOut = aileronOut-1

                        print "aileron set: %f" % (aileronOut)
                        fg.write("set /controls/flight/aileron %f\r\n" % (aileronOut))
```

Figure 3: Python code

4. CODE STANDARD

Since we have been only two people working on software and this assignment is a proof of concept our focus, when coding, has been on functionality.
However, to ensure better readability of the code we have used this very simple code standard:

4.1. Naming

Variables

- The variables uses logical names that makes the function easy see.
- Always starts with lowercase character. If the name is made up by several words the next word start with an uppercase. Example: int joystickStepElevator.

Function names
- Always starts with lowercase character. If the name is made up by several words the next word start with an uppercase. Example: void joystickElevatorOneStep().

Defines
- Always uppercase letters.
- Words separated by "_".

Constants
- Always uppercase letters.
- Words separated by "_".

Function- and variable prefixes
- "is" to ask a question about something. Whenever someone sees *Is* they will know it's a question.
- "get" get a value.
- "set" set a value.

Pointer variables
- Place the * close to the variable name not pointer type
- Example: char *rudderStep;

4.2. Comments

Variable comments
- Single line commenting with "//"

Function comments
- Block comments on multiple lines
  /**
  *
  */

4.3. Formatting

One statement per line
We will only be using one statement per line.
Example:
```
char **a = 0;
char  *b = 0;
```

5. MAIN CONTROLLER CARD

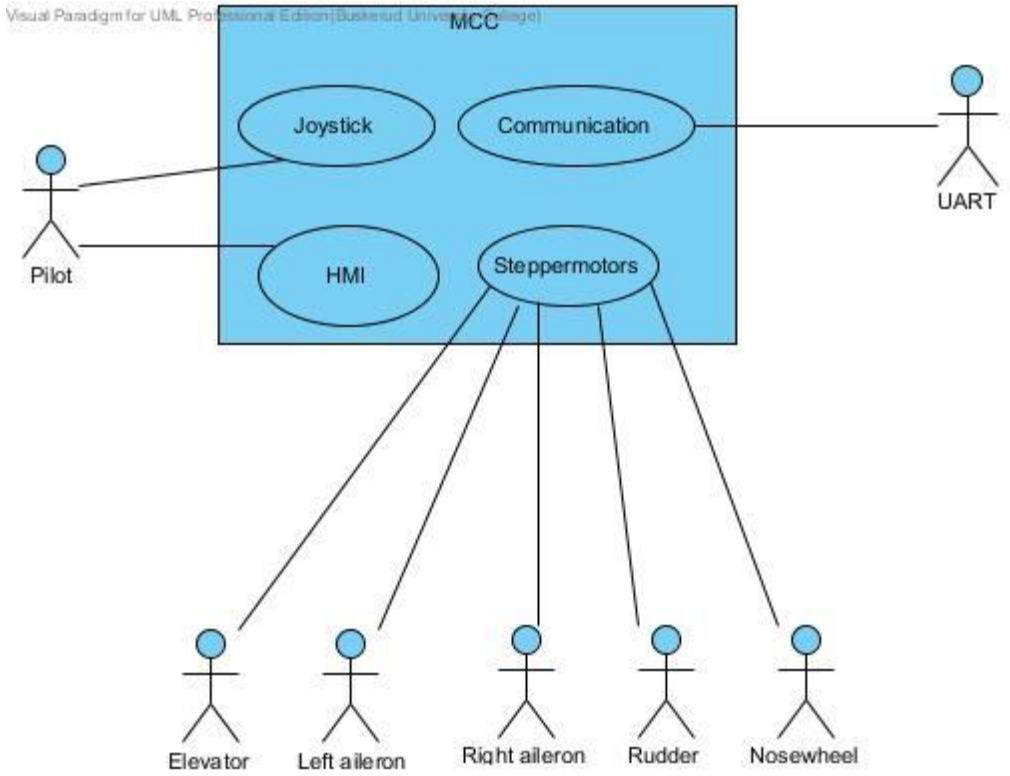

Figure 4: Use case diagram for Main controller card

Figure 4: Use case diagram for Main controller cardFigure 4 shows a use-case diagram of the MCC. This illustrates the actors, external sensors and influences that the MCC has to relate to.

Actors	Description
Pilot	Controls the aircraft with joystick and the HMI input panel.
UART	Sends and receives data to the supervisor.
Elevator	Elevator stepper motor
Left aileron	Left aileron stepper motor
Right aileron	Right aileron stepper motor
Rudder	Rudder stepper motor
Nosewheel	Nosewheel stepper motor

Table 3: Table of actors from MCC use case diagram

For a Class diagram of the MCC code, See Appendix: 13 MCC Software Class Diagram

For detailed explanation of the code and calculations performed please see the index.html file in the software documentation folder on the DVD.

6. SUPERVISOR CARD

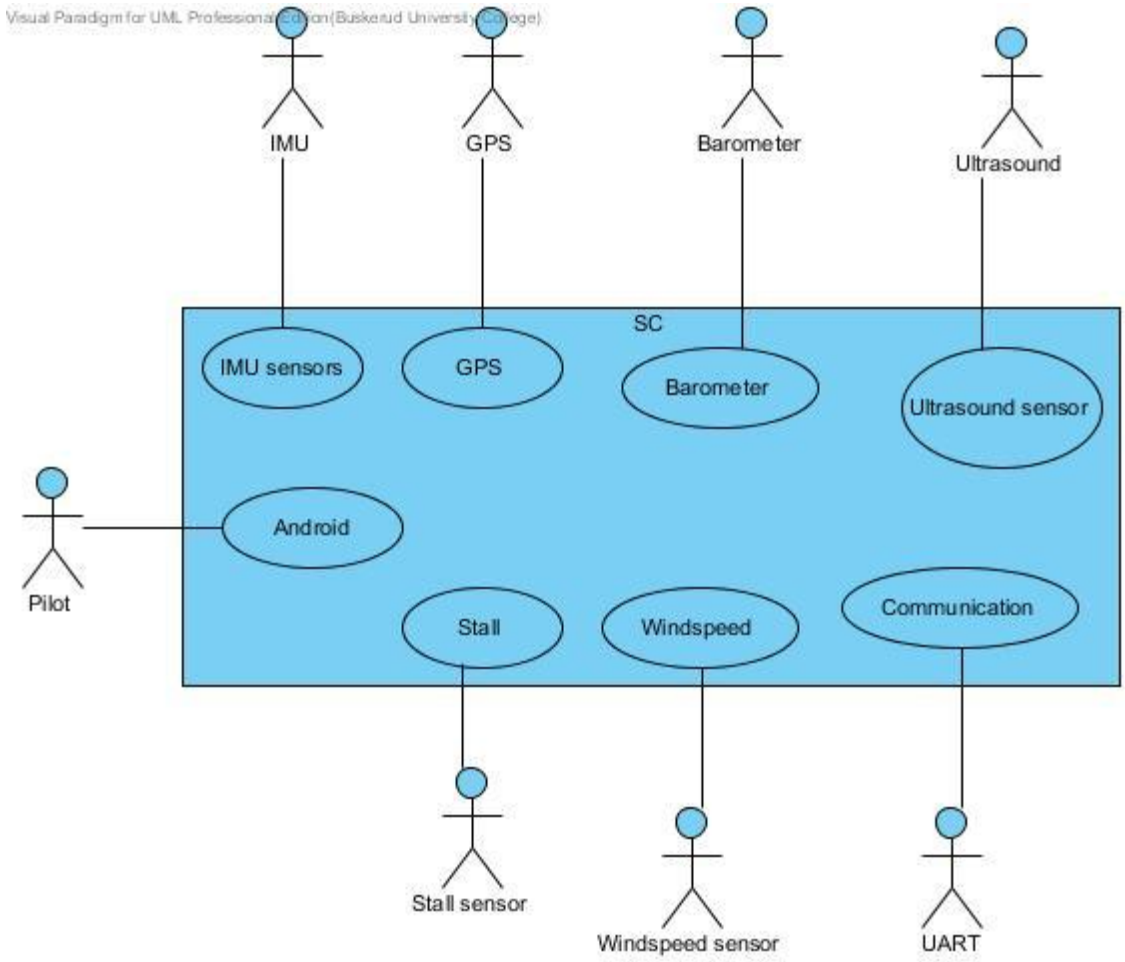

Figure 5: Use case diagram for Supervisor controller card

Figure 5 shows a use-case diagram of the SC. This illustrates the actors, external sensors and influences that the SC has to relate to.

Actors	Description
Pilot	Controls the aircraft by autopilot setpoints.
UART	Sends and receives data to the Main controller cards.
Stall sensor	Measures the angle of attack.
Windspeed sensor	Measures the wind speed.
Ultrasound	Measures the distance to the ground. (0-5m)
Barometer	Measure the atmospheric pressure
GPS	Calculates the aircraft position
IMU	Measures the rotational attributes

Table 4: Table of actors from SC use case diagram

For a Class diagram of the SC code, See Appendix: 14 SC Software Class Diagram

For detailed explanation of the code and calculations performed please see the index.html file in the software documentation folder on the DVD or dropbox.

7. COMMUNICATION PROTOCOL

To make the communication between the main controller cards and supervisor card as robust as possible we have made a protocol with the following principles:

- All messages are sent in ASCI.
- The SC will initiate all communication with either a GET – (request value) or SET- (set value) message.
- All messages sent from the SC to the MCC will be of length 7 characters. Header:3, body:3, delimiter:1.
- All messages sent from the MCC's to the SC will be of length 6 characters. Header:2, body:3, delimiter:1.
- Messages from the SC will be formatted with a header containing two fields: One containing the get/set character and the other the value in question.
- Messages sent from MCC's will be formatted with a header containing only one field, the value in question.
- All messages with end with a "|" character.

Table 5 and Table 6, shows some examples on messages that can be sent between SC and MCC.

From SC to MCC

Header field 1	Header field 2	Parameters	Delimiter	Description
<	ES	000	|	GET elevator step
<	EF	000	|	GET elevator feedback
>	Ac	XXX (000-001)	|	SET active

Table 5: Communication example from SC to MCC

From MCC to SC

Header	Parameters	Delimiter	Description
GE	XXX (000-999)	|	Answers the request

Table 6: Communication example from MCC to SC

A list of all the commands possible to send is found in the communication.c file in the source code. It is also easy to add more GET and SET functions if needed.

8. SIMULATOR

Name	
Flowchart:	
Part of	Simulator
Description	For the simulator we made a software code for the Arduino. This code read serial data from our system, processing it, and sends the modulated data out to flightgear. Al the float variables in flightgear have to be scaled from -1 to 1, excapt throttle that shall be unit scaled(we do not want negative throttle), this variables are: - Elevator - Aileron - Rudder - Throttle The 3 first variables do we got from our system. The throttle is read from an analog

	input at the arduino, and the variables for magnetos, starter, brakes and gear down, is integers which get the values from switches connected to digital inputs at the arduino. Al these variables are 0 or 1, except magnetos which is modulated in the code to be 3 because flightgear required it to start the plane. To get communication with flightgear we need to write a XML-code. This code read the data that comes over the serial line one after one. To separate the data that comes over the serial line, we have to define a variable separator in the XML. An example of how to send the serial data from the Arduino, and how the XML is build are shown under: Arduino code: Serial.print(start); Serial.print(","); XML code: <line_separator>newline</line_separator> <var_separator>,</var_separator> <chunk> <name>Magnetos</name> <node>/controls/engines/engine/magnetos</node> <type>float</type> </chunk>	
Owner and date	Runar Løken	16.05.2012

9. REVISIONS

Rev	Description	Date	Name
0.1	Made template rev 0.1	24.02.2012	A.G
0.2	Made software description for MCC	24.02.2012	R.L
0.3	Updated class info.	19.04.2012	K.M
0.4	Making software description for simulator	15.05.2012	R.L
0.5	Added research chapter, communication protocol, MCC and SC flowcharts and UML diagrams	28.05.2012	K.M T.A

Fault-Tree Analysis

Compact Fly-By-Wire System

Version	1.0
Category	Released
Issue Date	29.05.2012
Made by	A.G / S.A
Checked by	A.G
Approved by	Knut Brødreskift

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1. PURPOSE

Since no system is perfect, and our system needs to be as reliable as possible, it is a necessity to inspect the fault probability of the system. The easiest way to do this is to deduce a failure analysis in which an undesired state of the system is analyzed using Boolean logic to combine a series of lower-level events. By dividing our system in to smaller subsystems we can assure less error work probability, and less system analysis. Afterwards the subsystems are integrated to form the whole well analyzed complete system.
To illustrate the fault tree diagram we will use logic gates symbols.

1.1. Explanation to the MTBF numbers

A lot of the MTBF numbers are not mapped, such as “sharp objects fracture copper path” and the like. So we have calculated a number for these events. Other events are documented.
When the probability for an event is so small it in practice can be neglected we have put it to 2,000,000 hours (230 years).

To see the calculations we have on the MTBF numbers see: Excel-diagram

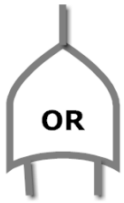
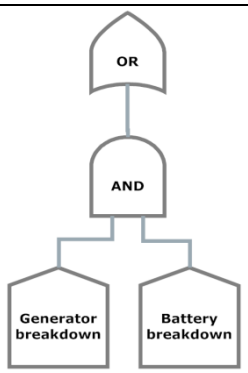
1.2. List of MTBF numbers

Event name	MTBF (Hours)	Scientific Number	Description
Broken copper path	2,000,000	$5.E^{-7}$	The copper path can I practice not be broken without excessive external force. In that case the aircraft should be inspected also.
Sharp objects fracture copper path	2,000,000	$5.E^{-7}$	The PCB’s will be located in an assigned box with an IP degree of protection. This event is therefore close to neglect able.
Mechanical wear creates fracture on copper path	2,000,000	$1.E^{-6}$	PCB’s are known to have a long expected life span. The PCB’s are protected inside a box.
Broken wires	200,000	$5.E^{-6}$	Bad connection points are often the reason for an electrical failure. That is however why there will be used robust terminals and connectors.
Conductive debris creates shortcut on copper path	2,000,000	$5.E^{-7}$	Additionally to the box where the PCB’s are located and protected, the top and bottom layer of the PCB’s are also coated with a protective insolating film.
Moisture creates shortcut on copper path	700,000	$1.34E^{-6}$	Even though the PCB’s are protected inside an IP coded box. Moisture may get in during service and such. The chances for a shortcut as a result of this however are very small.
broken wire shortcuts copper path	1,000,000	$1.E^{-6}$	If there is bad connections, or cables that are broken, they may shortcut on the PCB where the components are placed, or on terminals.
Vibrations cause unit to loosen	500,000	$2.E^{-6}$	The probability of this event is reduced as much as possibly by using through-hole components.
Corrosion cause bad connectivity	500,000	$2.E^{-6}$	If moisture gets into the box, there is a possibility of corrosion. Regular service and checks on the system is therefore required to prevent this.
Joystick Locks	2,000,000	$5.E^{-7}$	The likelihood that something physically blocks the joystick during flight is very small.

Joystick breaks	2,000,000	$5.E^{-7}$	In order to break the joystick, excessive force must be applied. This would probably happen when entering, exiting or loading the plane when on ground.
Joystick sensor fails	2,000,000	$5.E^{-7}$	We advice Equator Aircraft to use Hall sensors for the joystick. There is no mechanical contact inside these sensors, and they are known to be way more reliable than normal resistive potentiometers.
Generator breakdown	10,000	$1.E^{-4}$	This number is taken from: http://src.alionscience.com/pdf/TypicalEquipmentMTBFValues.pdf The equator crew will however produce its own biodiesel generator, so this number might have to be adjusted when the generator is tested. However bio-diesel engines are known to be long lived. So our MTBF number is probably too low. This is done on purpose.
Battery breakdown	3,000	$3.33.E^{-4}$	The equator crew has not yet decided on a battery package. So we picked a low MTBF number on purpose, to be sure it would be close to or less than the actual MTBF. Ref: http://alternative-energy.6pie.com/batteries/lifespan-of-batteries.php (one year = 8760 hours)
MCC fuse blows	1,000,000	$1.E^{-6}$	The chances of a fuse blowing without being overloaded are rather small.
SC fuse blows	1,000,000	$1.E^{-6}$	The chances of a fuse blowing without being overloaded are rather small.
External heat	1,000,000	$1.E^{-6}$	All the PCB's are placed at different locations sealed off from other equipment. And they are sufficiently cooled.
Dislocation of heat-sink	500,000	$2.E^{-6}$	The heat sink for the motor controllers will be glued on by a special thermally conductive paste, it is very strong, and due to the small weight of the heat sink, it will be resistive to vibrations.
Dislocation of sensor	500,000	$2.E^{-6}$	By accident or poor mounting the sensor may be dislocated, and give wrong feedback to the system.
Mechanical error on sensor	500,000	$2.E^{-6}$	The Sensor might not be working because of mechanical reasons
Fraction on cable	500,000	$2.E^{-6}$	The cables from the sensors to the MCC's might be fractured
Electrical error on sensor	500,000	$2.E^{-6}$	The sensor might be leading the output signals to ground. Or it might simply not work.
Wire loosen from sensor	200,000	$5.E^{-6}$	Connectors and terminals are often the weakest link
Mechanical disturbance on sensor	300,000	$3.33.E^{-6}$	Something might come between the sensor and the control plane and interfere on the sensor output signals
HMI switch breaks	1,000,000	$1.E^{-6}$	We have not yet decided on what switches to use on our Analog HMI Panel, as this is not a high priority. We have therefore set a sensible MTBF number

1.3. Explanations to the diagrams

Here is a description of all the logic symbols used in the diagrams. We Made the FTA diagrams in order to see which events affect which event, how it is affected and the consequence of it. The diagram is also used to produce the Excel tables, where we calculated the MTBF numbers.

Logic symbol	Standard Definition
	The AND gate multiplies two or more events together. This means that in order for the consequence to occur, both events need to happen at the same time. This reduces the chances dramatically for something to happen.
	The OR gate adds two or more events together. This means that in order for a consequence to occur only one event need to happen. This increases the chances for something to happen.
	This symbol represents a basic event. The event represents things that happen, for example: “sharp objects fracture copper path”.
	This symbol represents the product of two or more events. And is calculated by the AND or the OR gate.
	In our diagram the external event represents the battery breakdown or the generator breakdown, this is events that have a direct impact on our system, but is external events that we cannot influence.
	This logic gates combination with the OR gate directly after the AND gate is generally not a common way to do it. But we have decided to do it like this just to save space and time on the drawing. There would normally be a consequence between the AND and the OR gate. However since this combination with the battery and the generator is used so often we wanted it to use as small space as possible. The result is still the same.

2. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	RunarLøken
O.R.	Ole Riiser
FTA	Fault Tree Analysis
MTBF	Mean Time Between Failure
IP Code	IP degree of protection. A number telling you how waterproof & dustproof a capsule, box or component is.

3. TEMPLATE

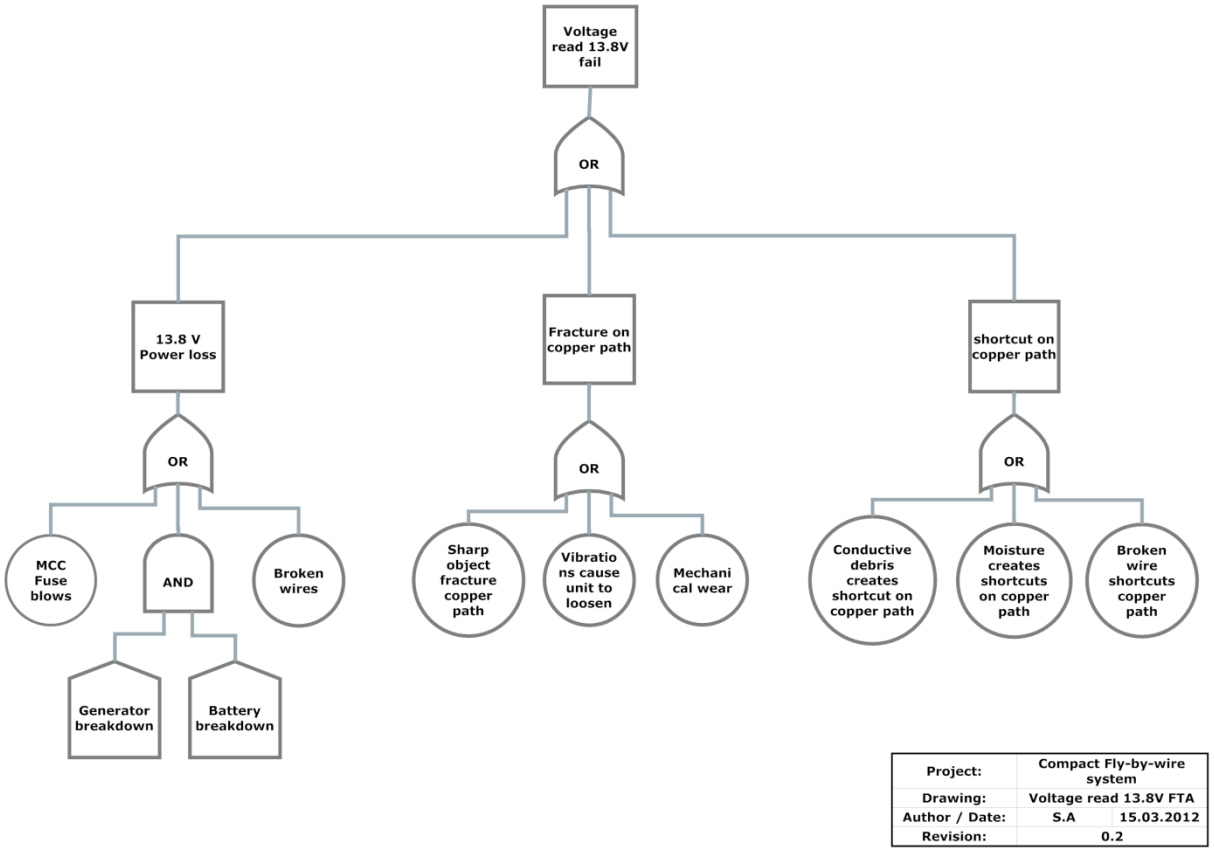
3.1.1. **Name of the subsystem**		
Fault tree diagram:		
Part of	System?	
Description of the subsystem	Function?	
Consequence of total failure:		
MTBF:	X hours between each failure. Ref (excel diagram)	
Time spent (Hours)	3 hours	
Owner and date	A.G	02.03.2012

4. COMMON UNITS FOR SC AND MCC

To keep the document as short as possible we have made this chapter for components that are used on both the MCC and the SC.

4.1.1. Voltage read 13.8V

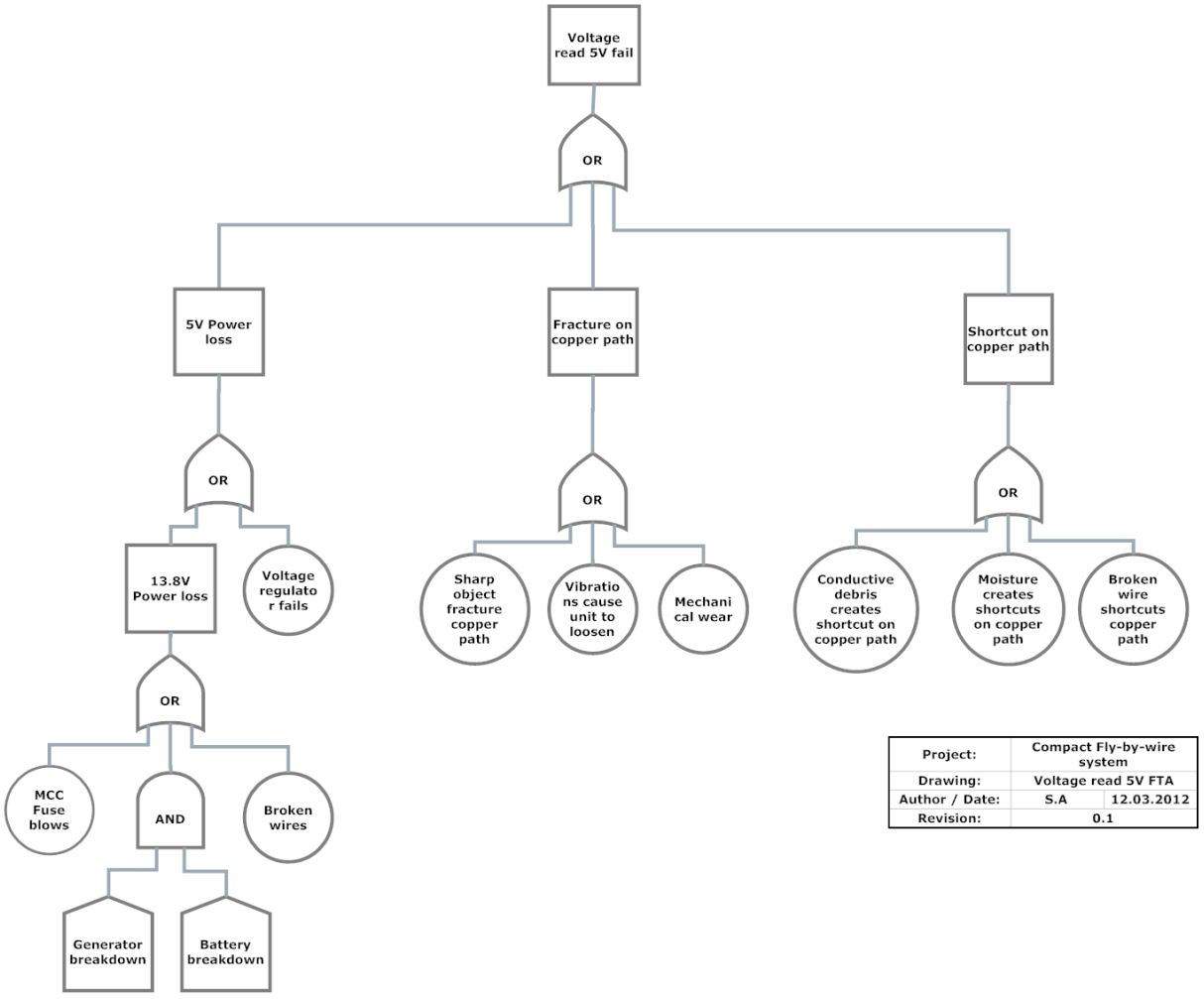
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The voltage reader measures the voltage right after the connector on the MCC.	
Consequence of total failure:	The pilot will not get any information about the voltages on the card. If only the Voltage reader fails, it will not affect the flights maneuverability. If the pilot wants to get the voltage information, he will have to change MCC.	
MTBF:	83,589.0 Hours Between failures. Ref: Excel-diagram\Common Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	12.03.2012

4.1.2. Voltage read 5V

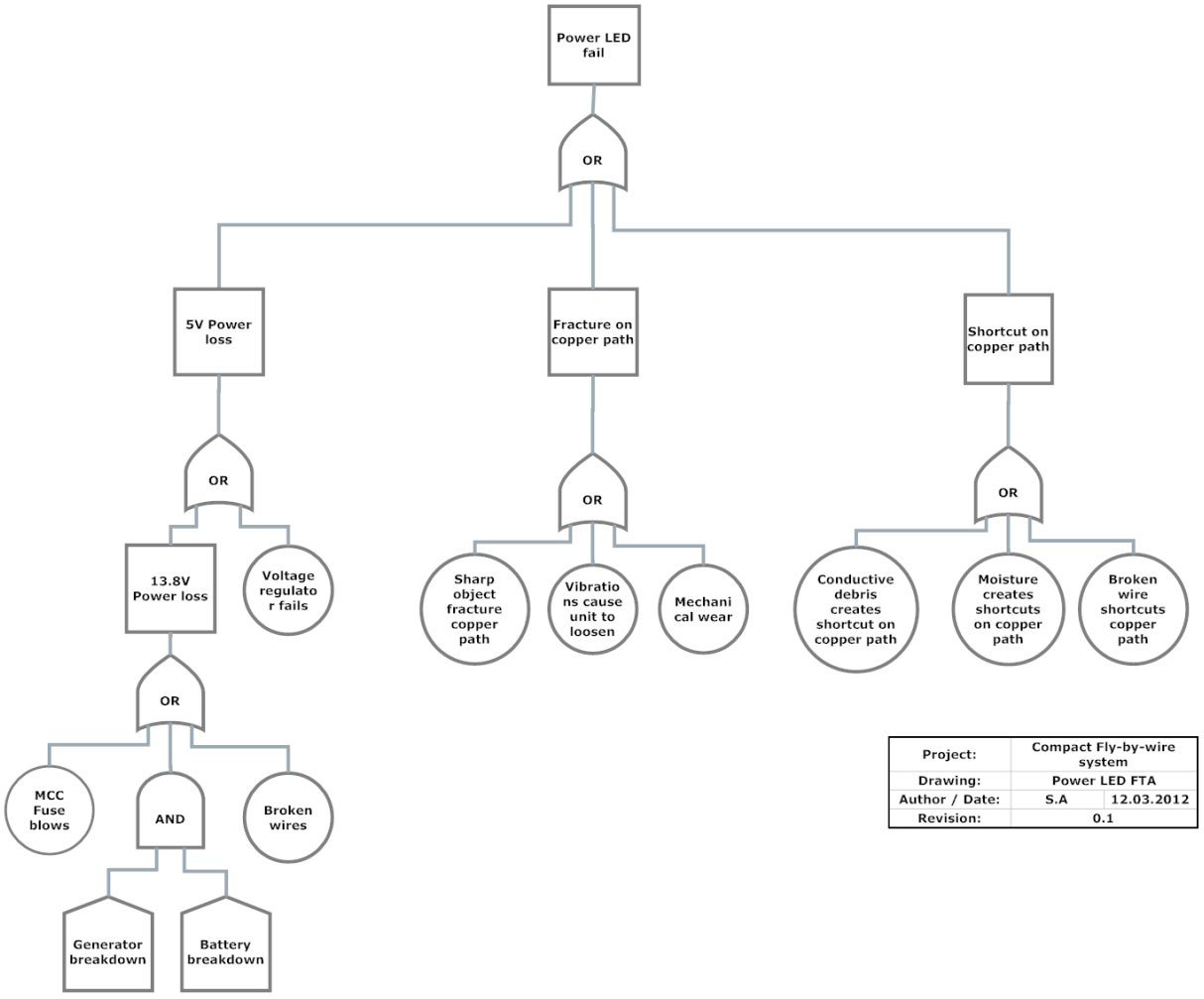
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The voltage reader measures the voltage right after the 5V voltage regulator on the MCC.	
Consequence of total failure:	The pilot will not get any information about the voltages on the card. If only the Voltage reader fails, it will not affect the flights maneuverability. If the pilot wants to get the voltage information, he will have to change MCC.	
MTBF:	36,412.2 Hours Between failures. Ref: Excel-diagram\Common Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	12.03.2012

4.1.3. Power LED

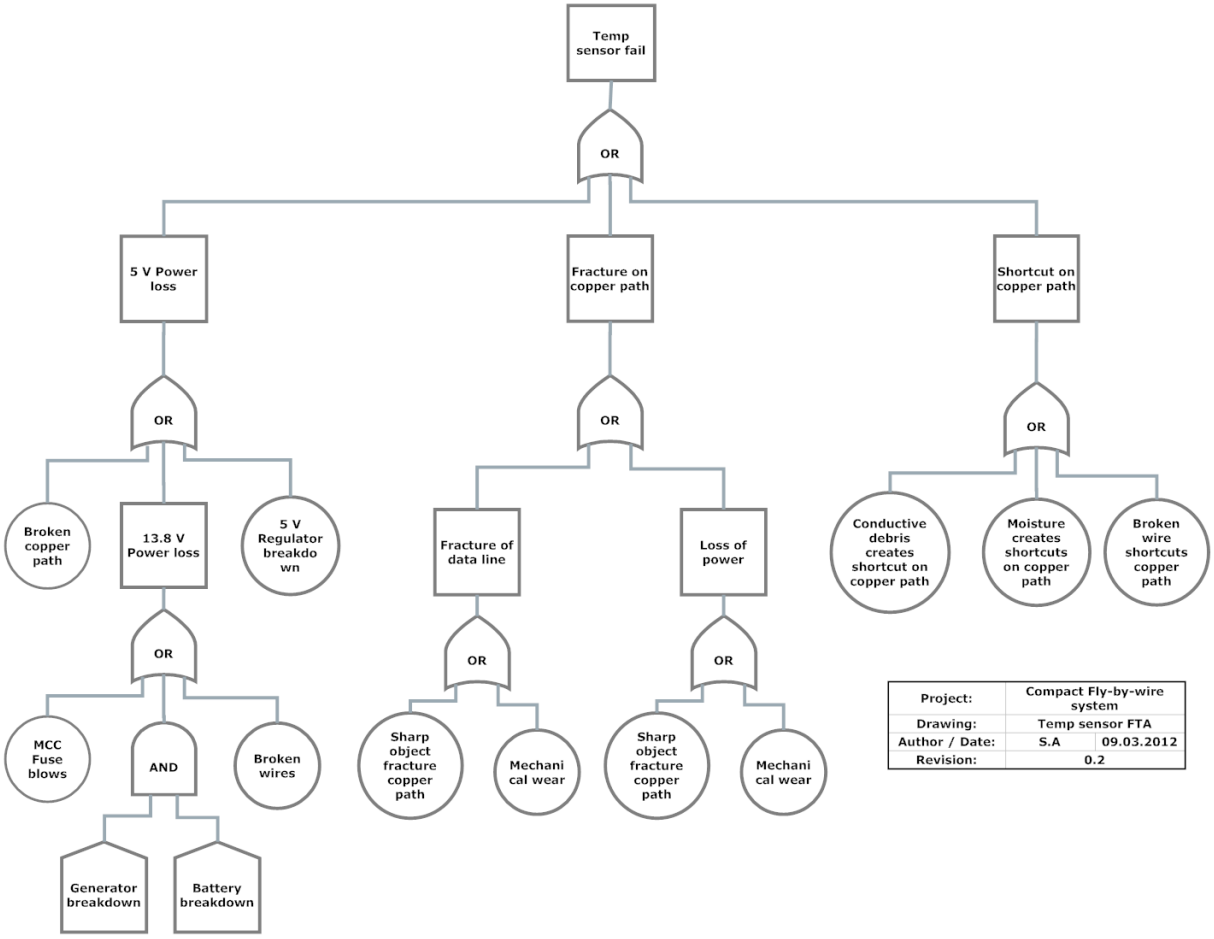
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The Power LED indicates whether the MCC is ON or OFF.	
Consequence of total failure:	The pilot will not get any information if the card is on or off. If only the Power LED fails, it will not affect the aircraft's maneuverability. If the pilot wants to see the power LED on, he will have to change MCC.	
MTBF:	36,412.2 Hours Between failures. Ref: Excel-diagram\Common Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	12.03.2012

4.1.4. Temp sensor

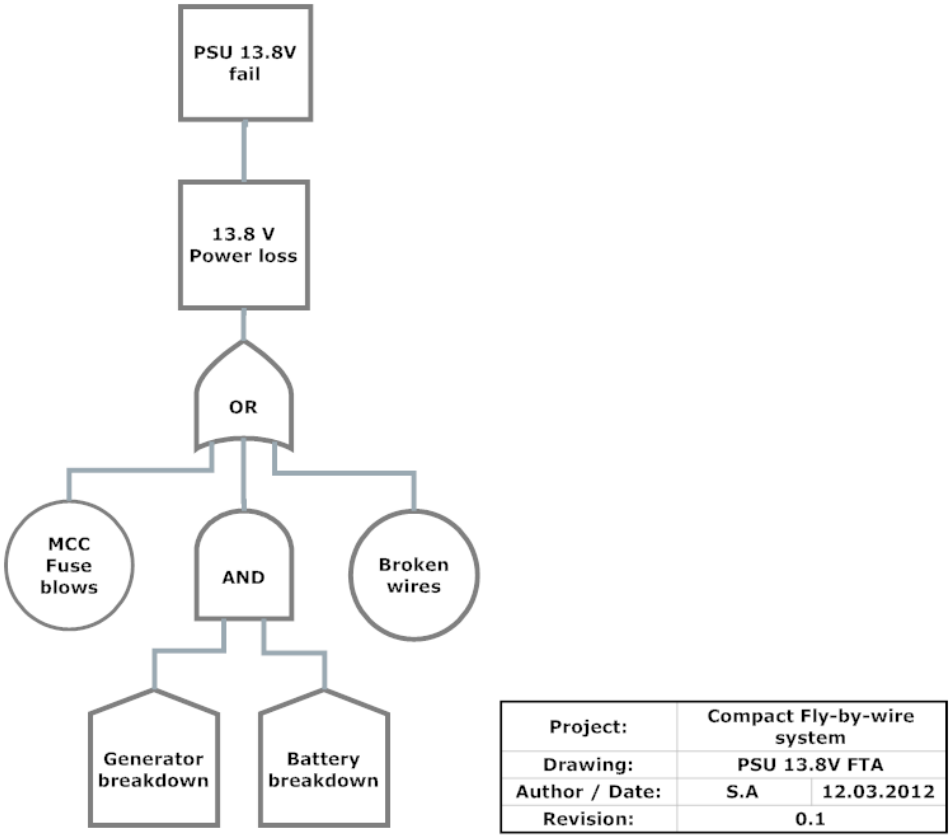
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The Temp sensor shows the temperature on the MCC.	
Consequence of total failure:	The pilot will not get any information regarding the temperature on the MCC. If only the Temperature sensor fails, it will not affect the flights maneuverability. If the pilot wants to see the temperature, he will have to change MCC.	
MTBF:	37,087.4 Hours Between failures. Ref: Excel-diagram\Common Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	12.03.2012

4.1.5. Power Supply 13.8V

Fault tree diagram:



Part of	MCC	
Description of the subsystem	The 13.8V is the main power supply, and supply all the MCC's and the SC with power.	
Consequence of total failure:	If the 13.8V fails, it might be the fuse, so another MCC might work.	
MTBF:	165,746.8 Hours between failures. Ref: Excel-diagram\Common Rev0.2.xlsx	
Time spent (Hours)	2 hour	
Owner and date	S.A / A.G	19.04.2012

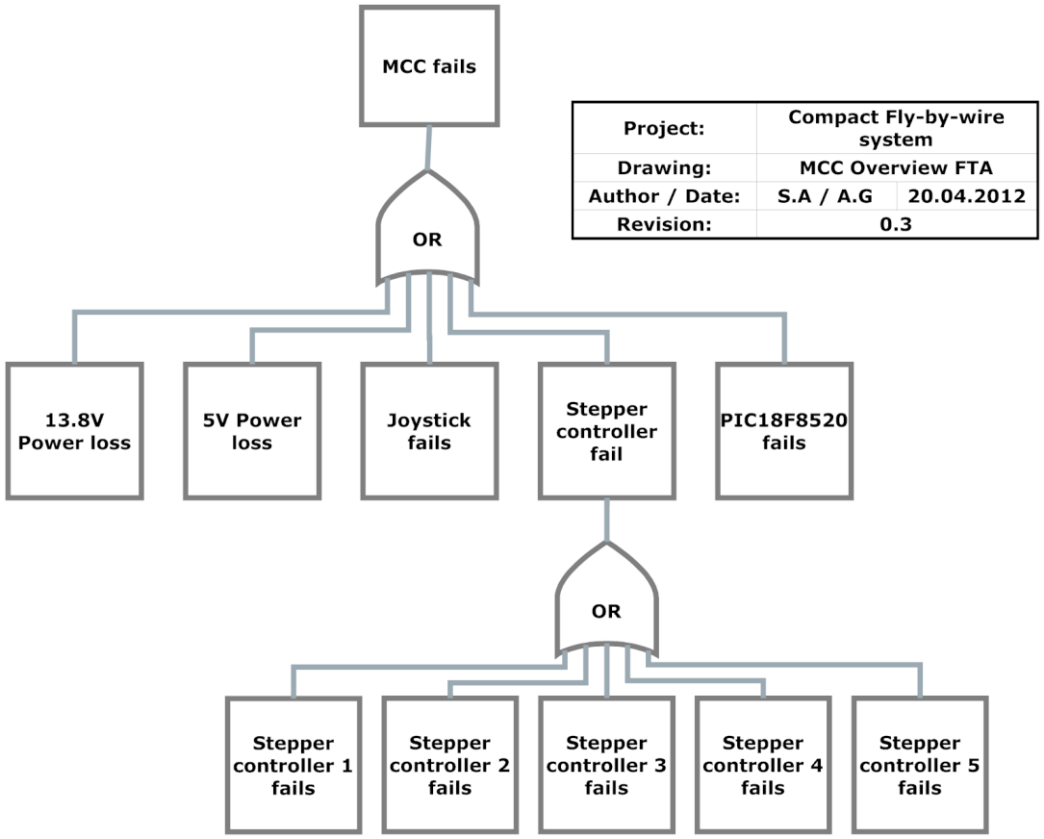
5. MAIN CONTROLLER CARD

5.1. Description to the chapter

We consider the MCC's as independent systems in this chapter, and divide them into several smaller subsystems to ensure a less extensive system analysis.

5.1.1. MCC FTA

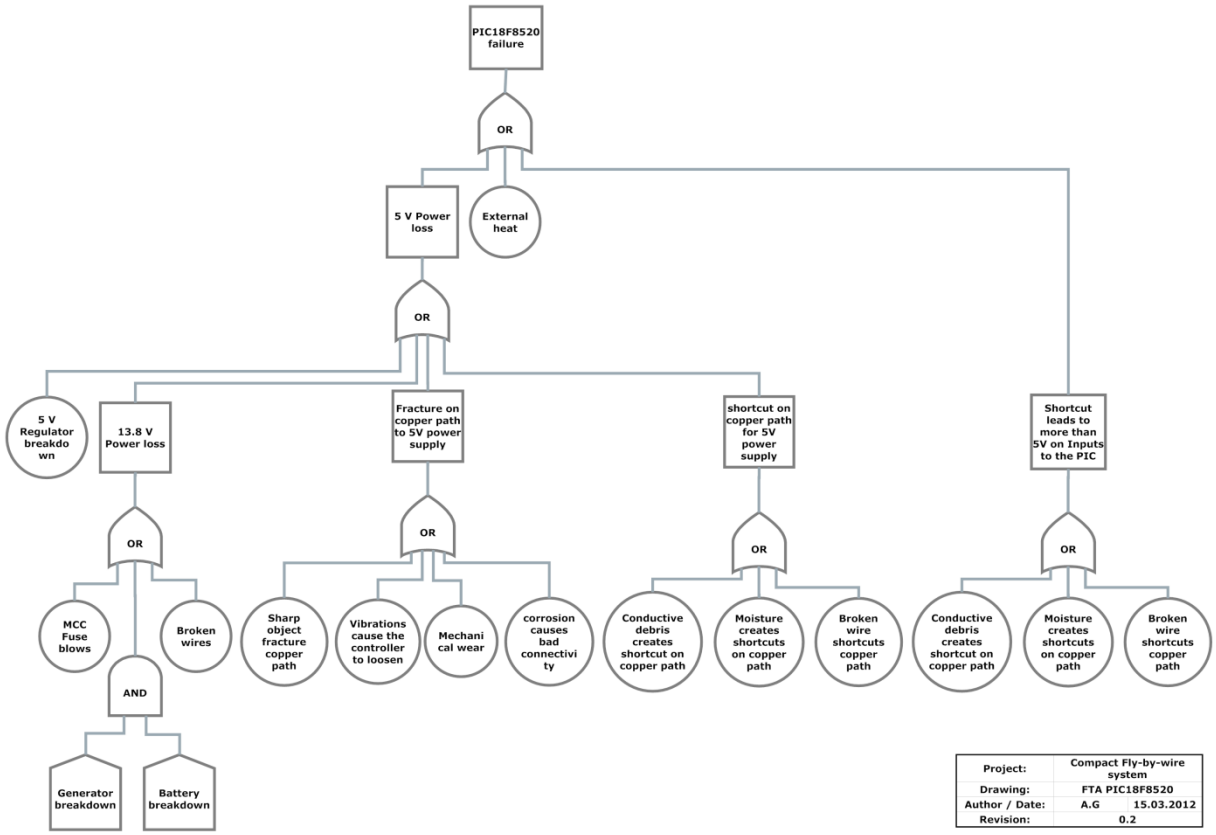
Fault tree diagram:



Part of	This is the FTA of the MCC.	
Description of the system	This is the entire MCC system. It is the MCC that controls the control surfaces on the airplane.	
Consequence of total failure:	Total failure of the MCC means that the airplane is uncontrollable. That is the reason why we have three of these doing the same job. If all of the three fails simultaneously the pilot then has two choices: 1 try to control the aircraft using the trim tabs on the control planes. 2 pull the emergency parachute.	
MTBF:	4,891.3 hours between failures. Ref: Excel-diagram\MCC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	S.A / A.G	18.04.2012

5.1.2. PIC18F8520

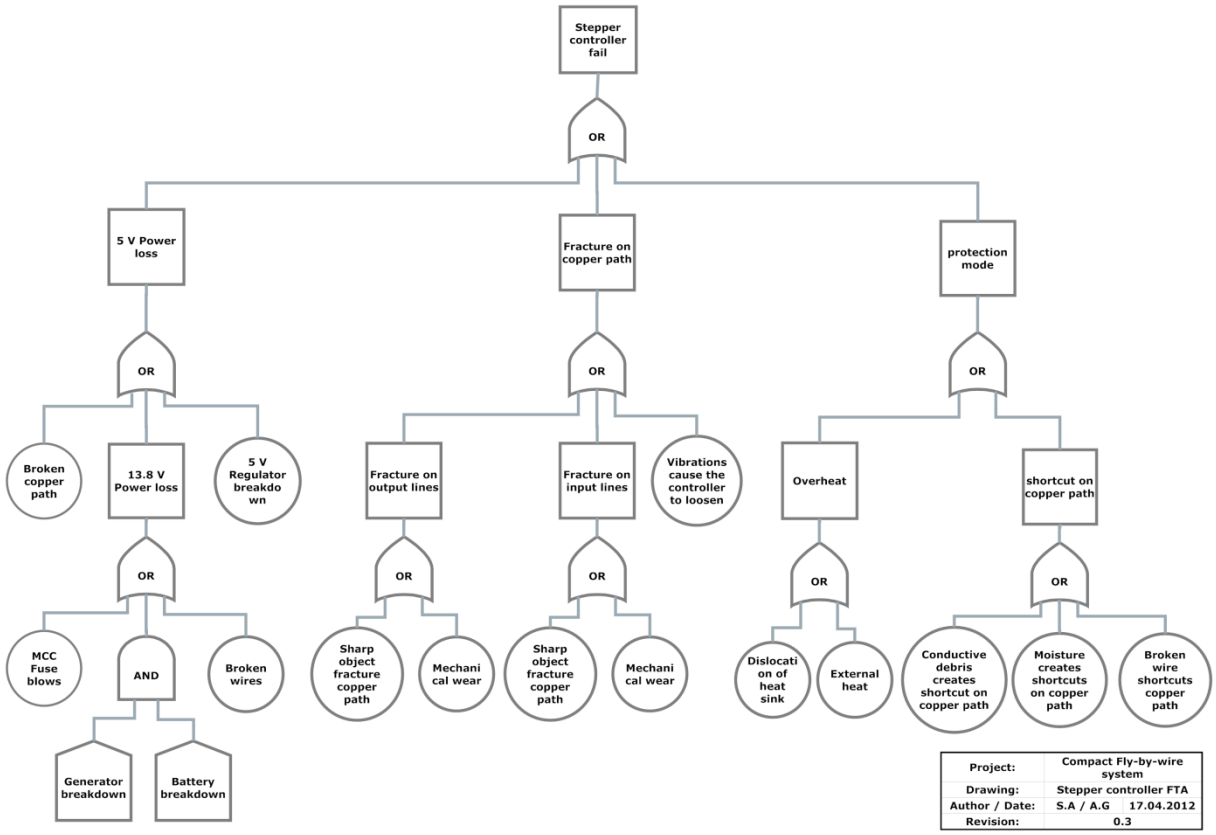
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The PIC18F8520 is the “heart” of the MCC, and it does all the calculations and handle all the I/O’s.	
Consequence of total failure:	If the PIC18 fails on the MCC, the MCC is useless, it will stop sending data to SC, and the SC will change the command to another MCC.	
MTBF:	55,895.8 hours between failures. Ref: Excel-diagram\MCC Rev0.2.xlsx	
Time spent (Hours)	3 hours	
Owner and date	A.G	18.04.2012

5.1.3. Stepper Controller

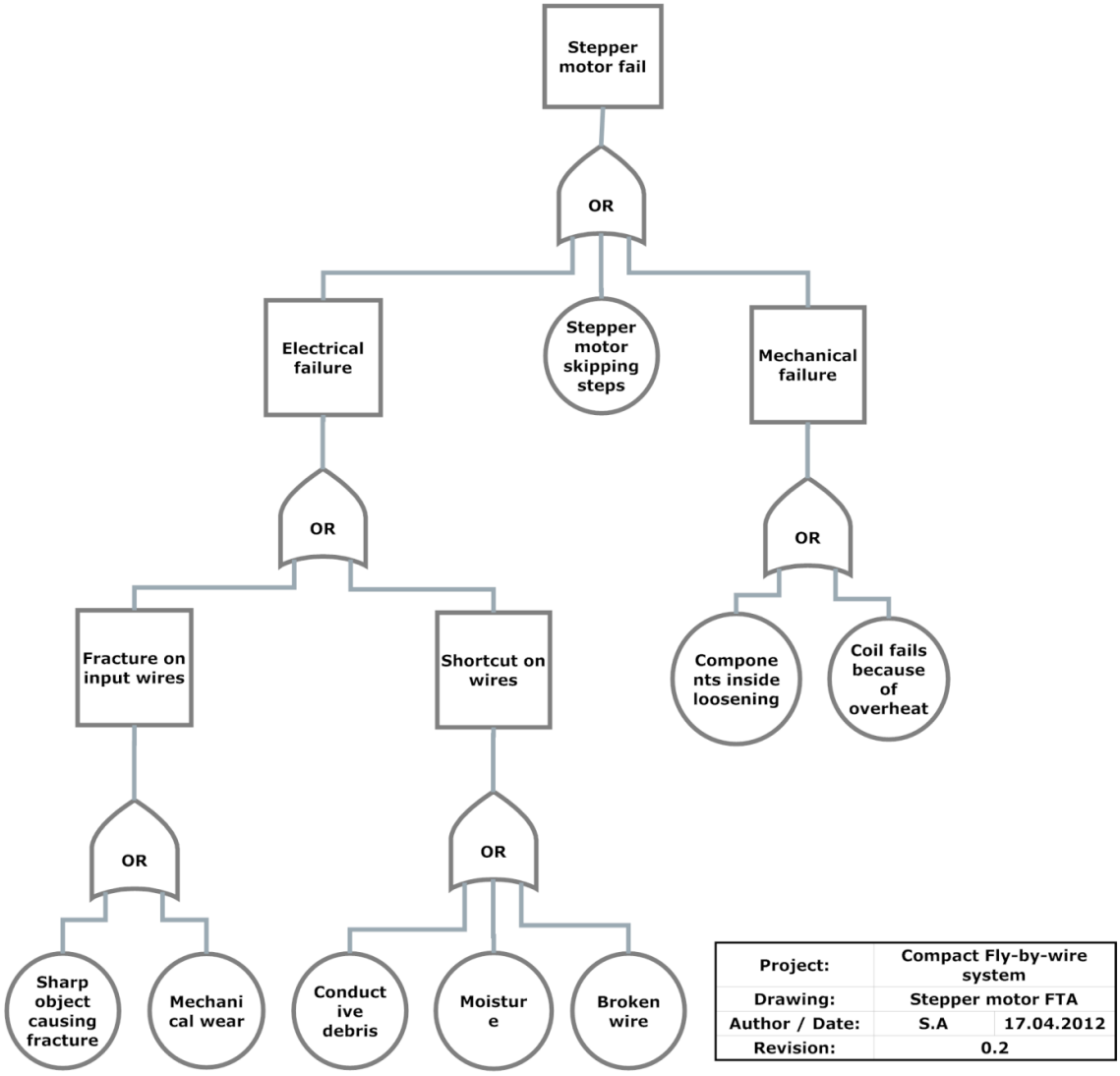
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The stepper controller receives commands from the PIC18F8520, and controls the stepper motor accordingly.	
Consequence of total failure:	If the Stepper motor controller stops working; the MCC receive feedback from the control plane sensors, and it will register a deviation between the desired position of the control plane and the actual position. The MCC sends a status report to the SC, and it will simultaneously change the color on the HMI LED from green to red.	
MTBF:	31,784.5 hours between failures. Ref: Excel-diagram\MCC Rev0.2.xlsx	
Time spent (Hours)	5 hour	
Owner and date	A.G / S.A	18.04.2012

5.1.4. Stepper motor

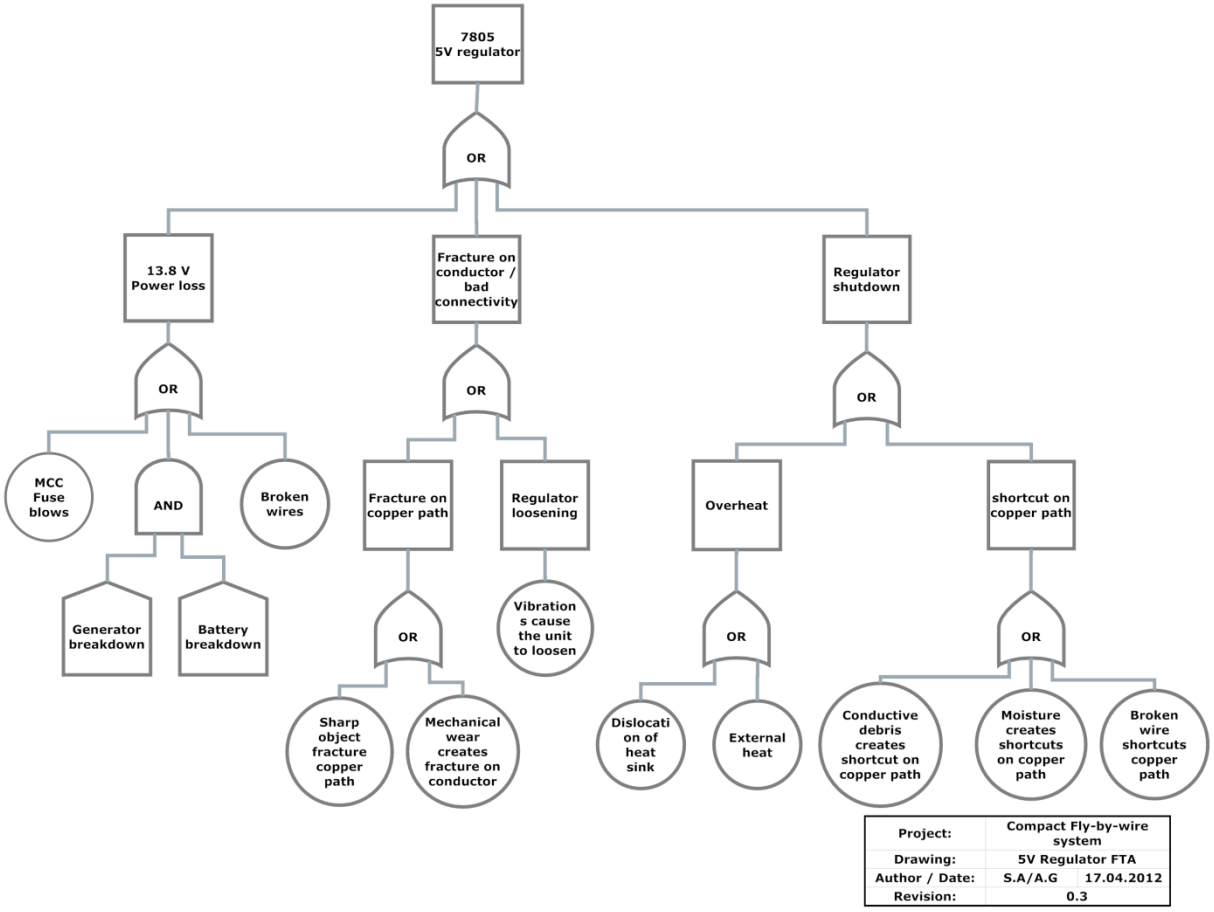
Fault tree diagram:



Part of	Common unit	
Description of the subsystem	The stepper motor receives commands from the stepper controller, and controls the control surfaces.	
Consequence of total failure:	If the Stepper motor stops working; the MCC receive feedback from the control plane sensors, and it will register a deviation between the desired position of the control plane and the actual position. The affected motor will not operate the steering surface and therefore the airplanes maneuverability will be affected.	
MTBF:	202,898.6 Hours between failures. Ref: Excel-diagram\MCC Rev0.3.xlsx The stepper motor produces more heat when not moving. To prevent the coils from overheating and eventually melting, we will develop å software function that switch one or two steps within a given period of time in order to move the strain on the coils. This only applies when the control planes (stepper motors) are still for a long period.	
Time spent (Hours)	3 hour	
Owner and date	S.A / A.G	19.04.2012

5.1.5. 7805 Linear Voltage Regulator 5V

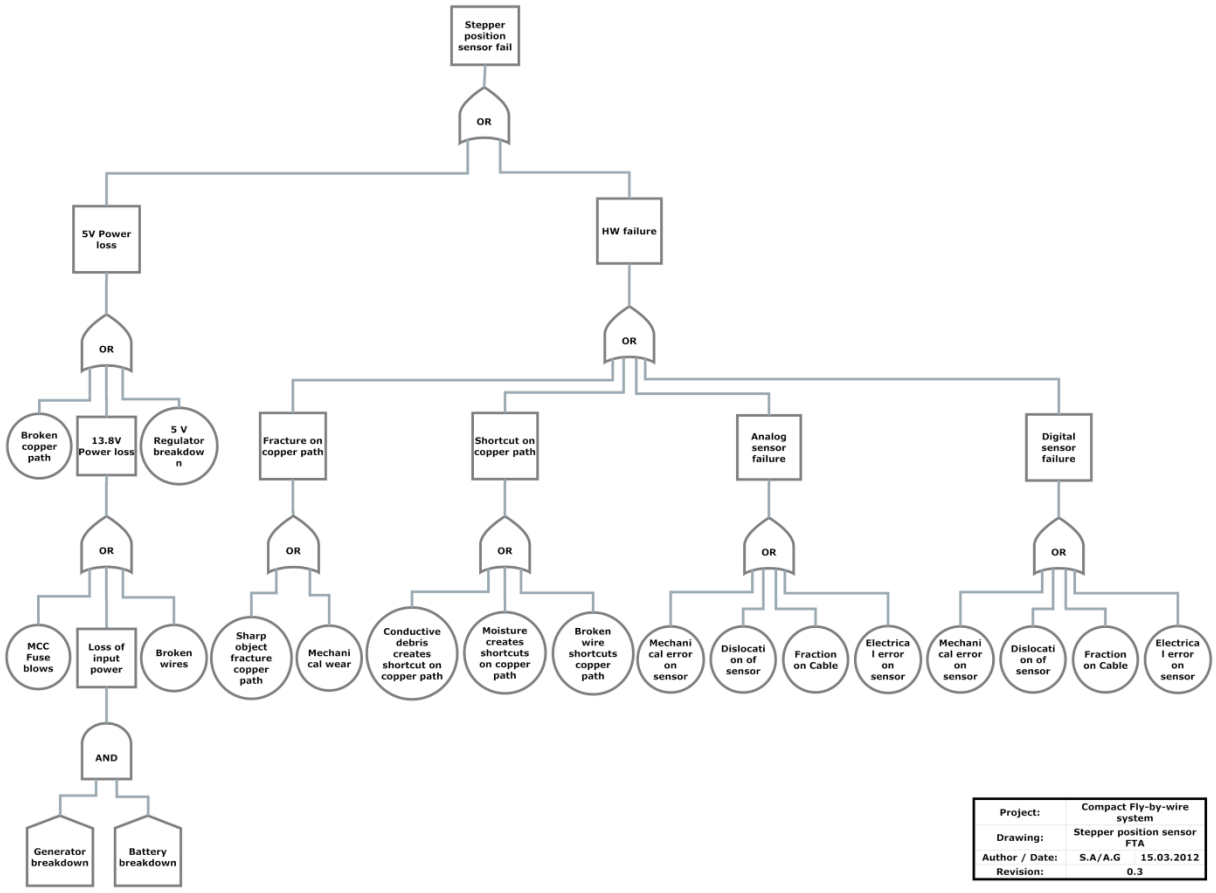
Fault tree diagram:



Part of	MCC	
Description of the subsystem	The 5V regulator will convert the 13.8V voltage into a linear 5V power supply for the Joystick and for the analog devices on the MCC	
Consequence of total failure:	If the 5V voltage regulator fails, this will lead to total failure of the MCC and the pilot has to change MCC.	
MTBF:	64,675.2 hours between failures. Ref: Excel-diagram\MCC Rev0.1.xlsx	
Time spent (Hours)	2 hour	
Owner and date	S.A / A.G	17.04.2012

5.1.6. Stepper position sensor

Fault tree diagram:

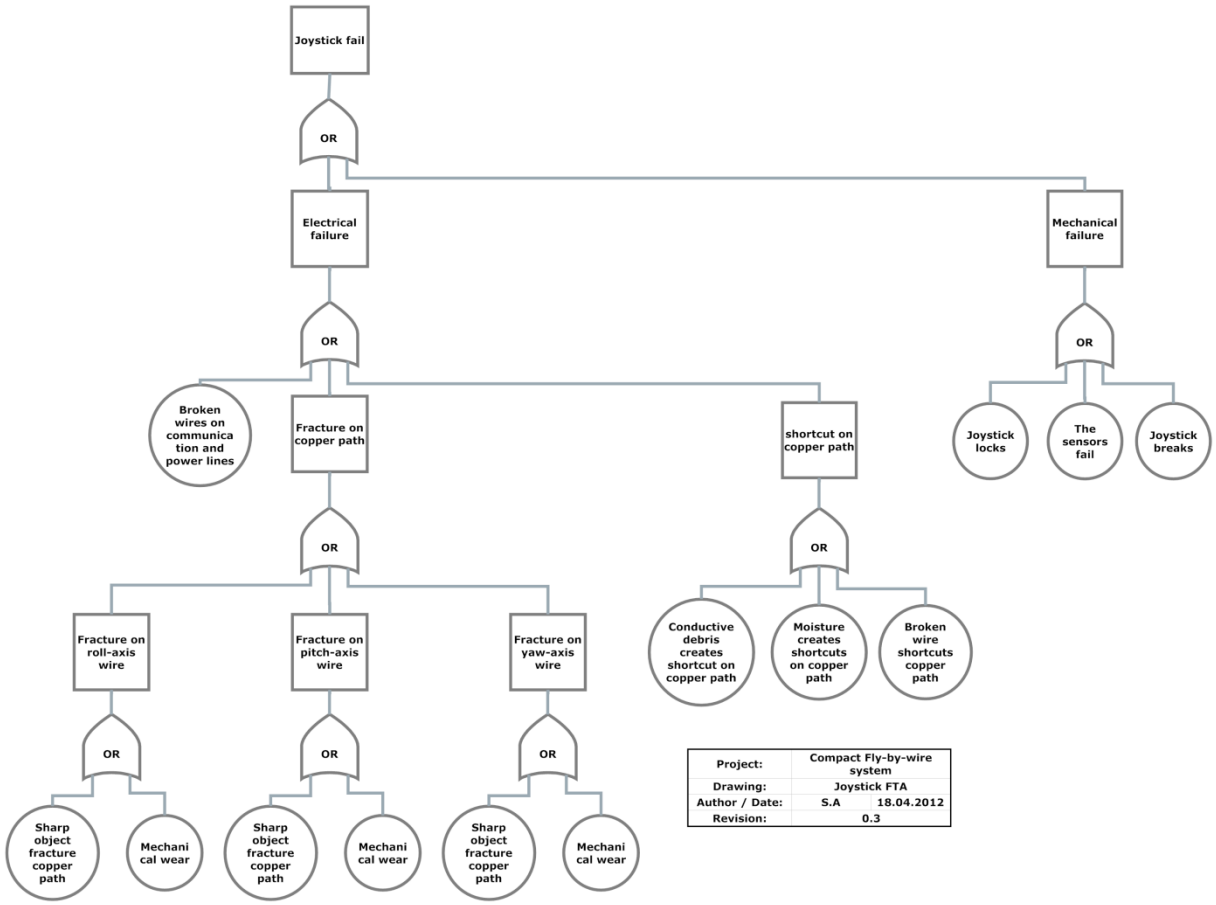


Part of	MCC	
Description of the subsystem	The Digital sensor reports to the MCC every time the control plane is in zero position. The Analog sensor measure the actual position of the control plane, and every time the control plane passes the zero position the MCC checks if the analog sensor is sending the right values according to the position, and it resets the “zero value” of the analog sensor on the MCC.	
Consequence of total failure:	The stepper motors can be controlled open-loop. Therefore, if only the sensor fails, it will not affect the flights maneuverability. But the MCC will not detect any errors if they occur. All the MCC’s will report the failure to the SC, the SC will give an alarm to the pilot and recommend the pilot to land and fix the problem.	
MTBF:	25,340.9 hours between failures. Ref: Excel-diagram\MCC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	S.A / A.G	18.04.2012

We are considering the joystick as a part of the MCC because every MCC is assigned its own set of axis sensors from the joystick.

5.1.7. **Joystick**

Fault tree diagram:



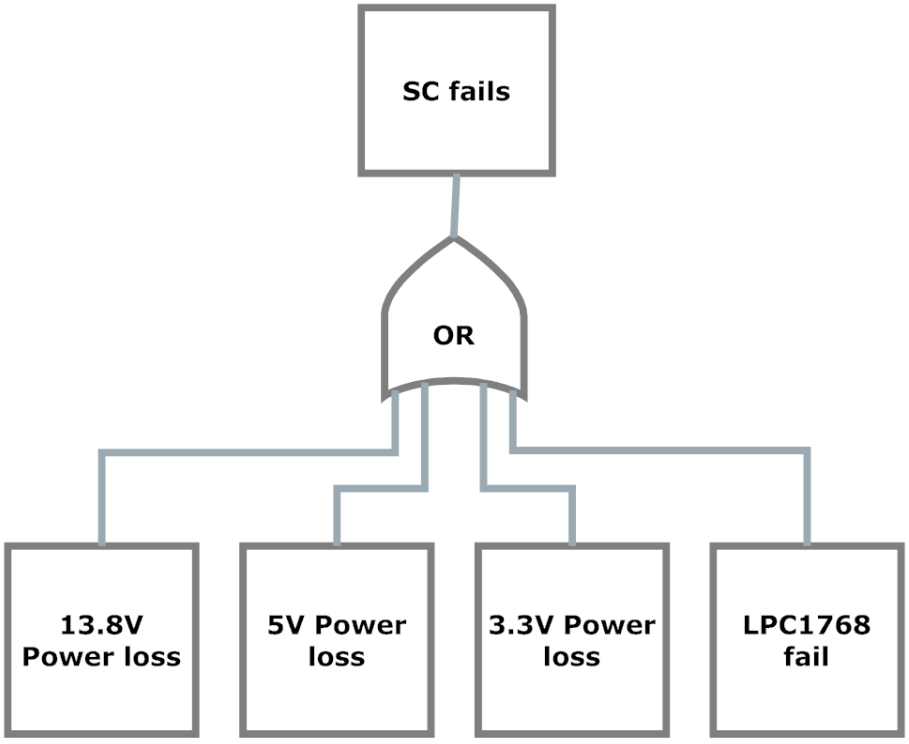
Part of	MCC	
Description of the subsystem	The joystick will transfer the pilot's desired action into electrical signals, which go to the microcontroller on the MCC and further control the control surfaces.	
Consequence of total failure:	If the joystick fails, the airplane will be out of control. We therefore have a triple-redundant joystick, where every set of the axes are connected to their own MCC card. If the mechanical failure occurs, the problem cannot be fixed by changing MCC, and the pilot will have to try to fix it. If not the system has failed.	
MTBF:	121,212.1 hours between failures. Ref: Excel-diagram\MCC Rev0.2.xlsx	
Time spent (Hours)	2 hour	
Owner and date	S.A /A.G	18.04.2012

6. SUPERVISION CARD

We consider the SC as an independent system in this chapter, and divide it into several smaller subsystems to ensure a less extensive system analysis.

6.1.1. SC FTA

Fault tree diagram:

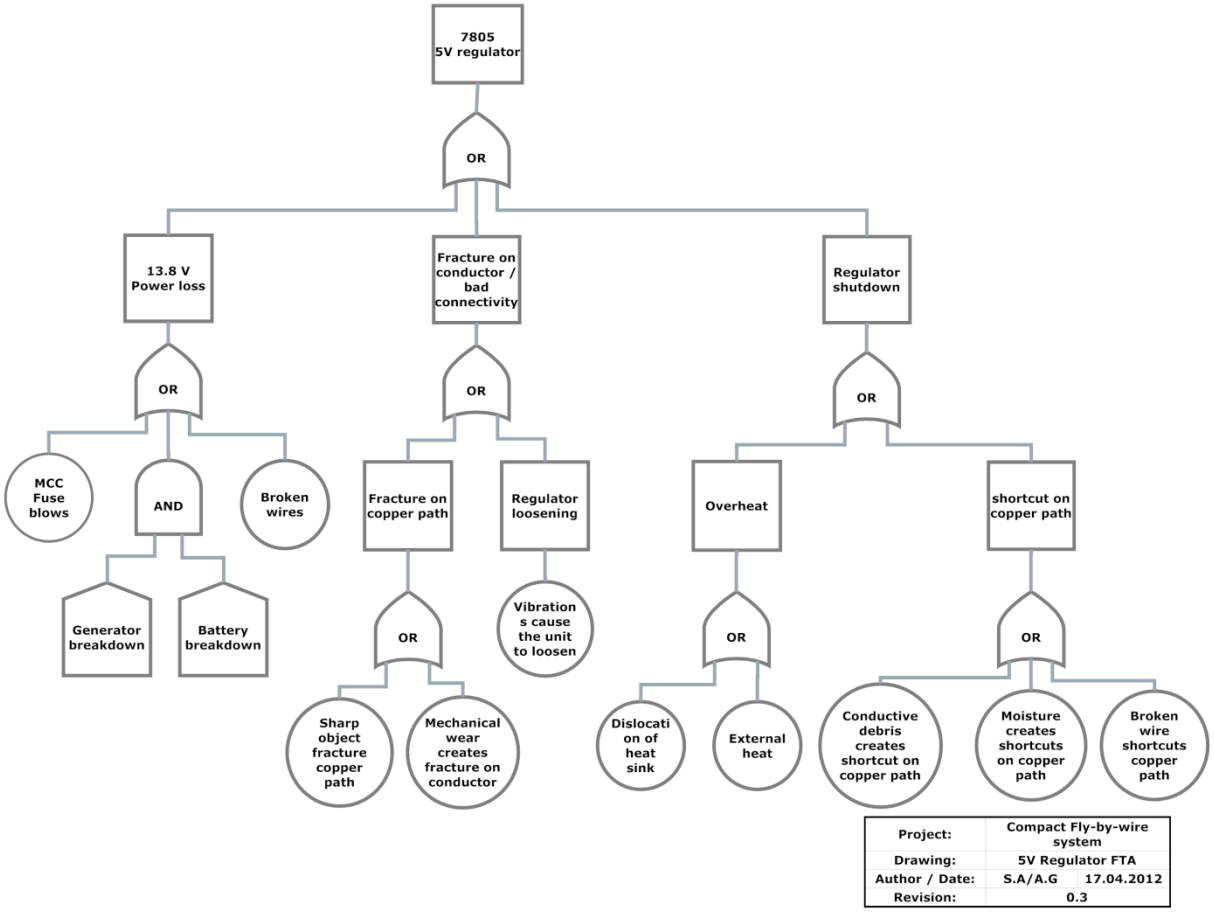


Project:	Compact Fly-by-wire system	
Drawing:	SC Overview FTA	
Author / Date:	S.A	17.04.2012
Revision:	0.2	

Part of	This is the FTA of the SC.	
Description of the system	This is the entire SC FTA system. The SC automatically chooses the operating MCC. SC can also be used to supervise the control inputs from the pilot and as autopilot.	
Consequence of total failure:	Total failure of the SC means that the airplane does not choose MCC by itself if it fails. Therefore the pilot has to manually choose which MCC who is operating by the HMI panel. The pilot will not have the extra functions to improve the overall flight experience either.	
MTBF:	9,976.7 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	S.A	19.04.2012

6.1.2. 5V regulator

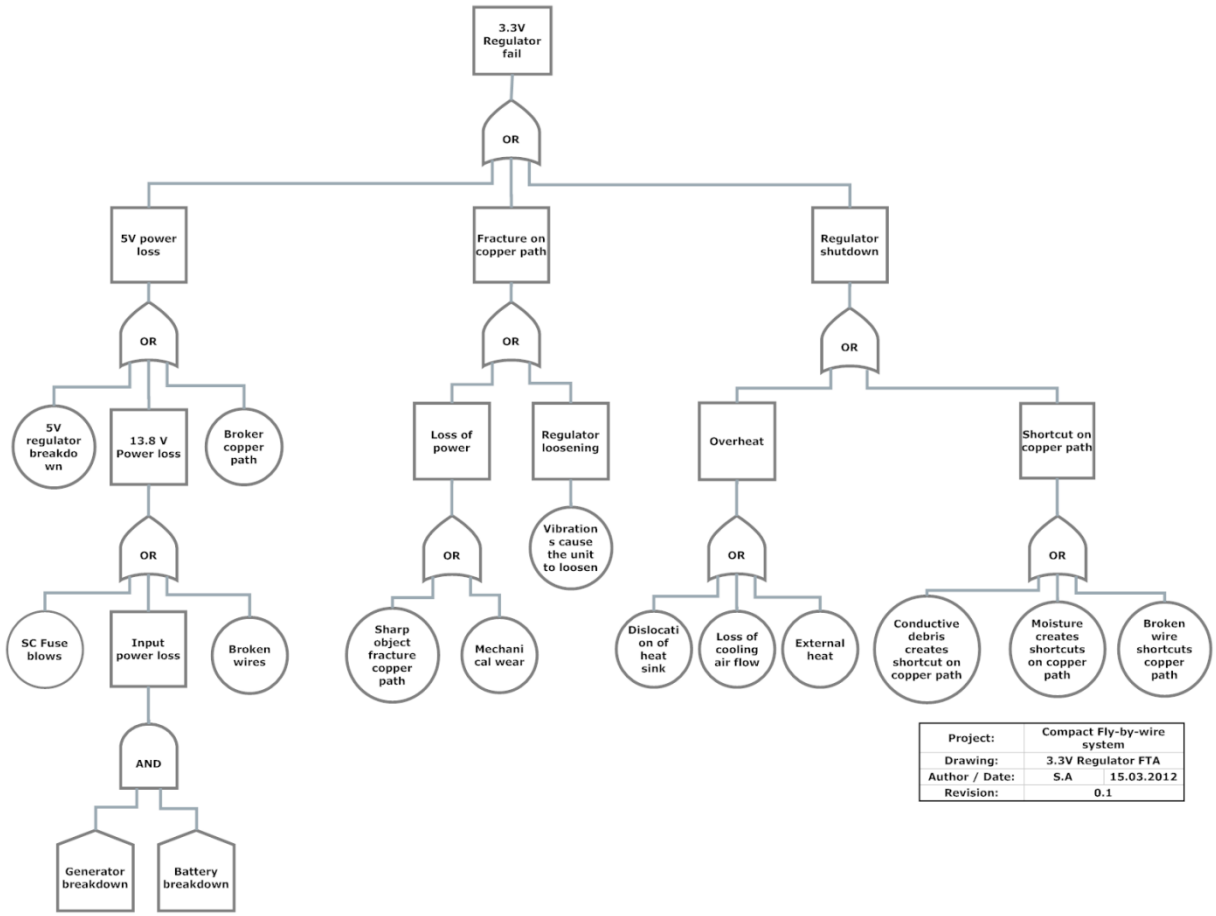
Fault tree diagram:



Part of	SC	
Description of the subsystem	The 5V regulator will convert the 13.8V voltage into a linear 5V power supply for the microcontroller on the SC.	
Consequence of total failure:	If the 5V voltage regulator fails, this will lead to total failure of the SC. This will lead to loss of all the functions the SC provide. The pilot therefore needs to change MCC manually if something happens, and will be warned by a light on the HMI that he needs to land the airplane and get the problem sorted out.	
MTBF:	66,836.6 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A / A.G	19.04.2012

6.1.3. 3.3V regulator

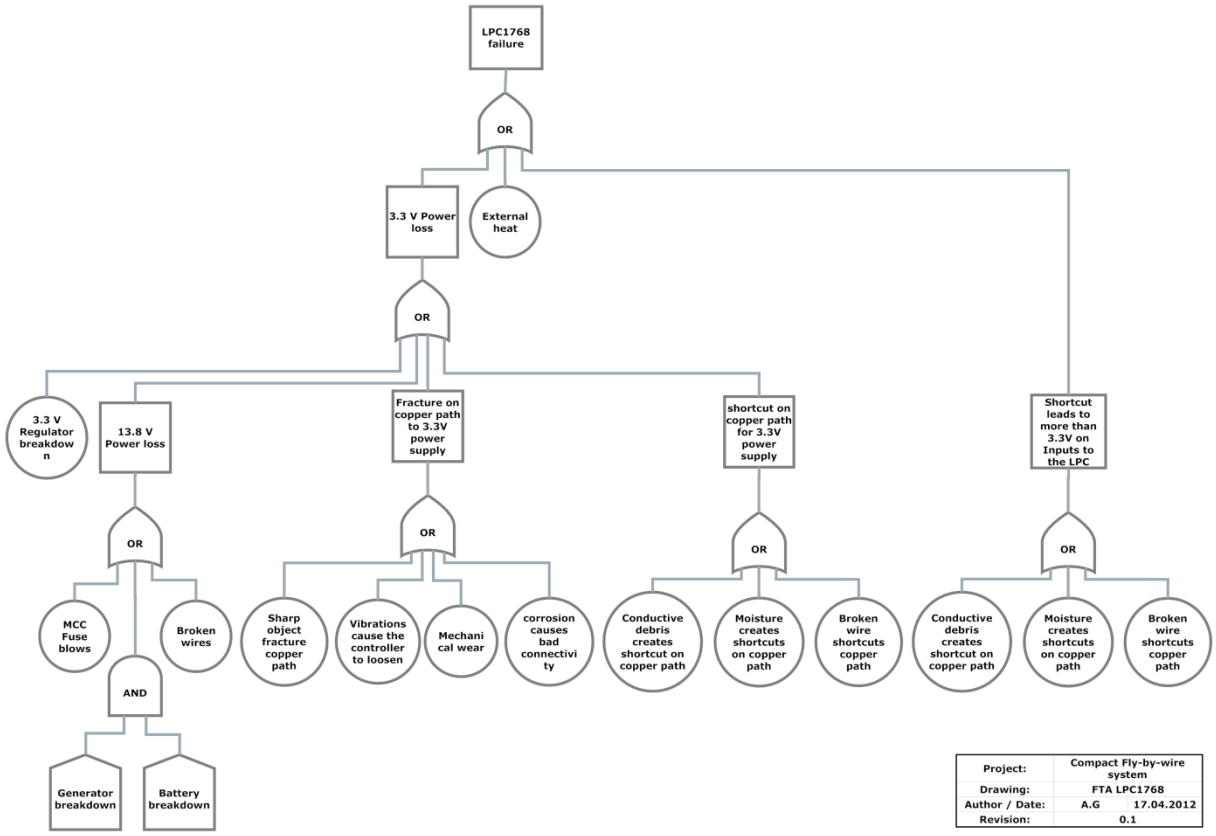
Fault tree diagram:



Part of	SC	
Description of the subsystem	The 3.3V regulator will convert the 5V voltage into a linear 3.3V power supply for the GPS, barometer and the IMC.	
Consequence of total failure:	If the 3.3V voltage regulator fails, this will lead to failure on the GPS, barometer and the IMC. The pilot will get a message through the SC LED which tells him that the SC is not working properly.	
MTBF:	32,869.1 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	19.04.2012

6.1.4. LPC1768

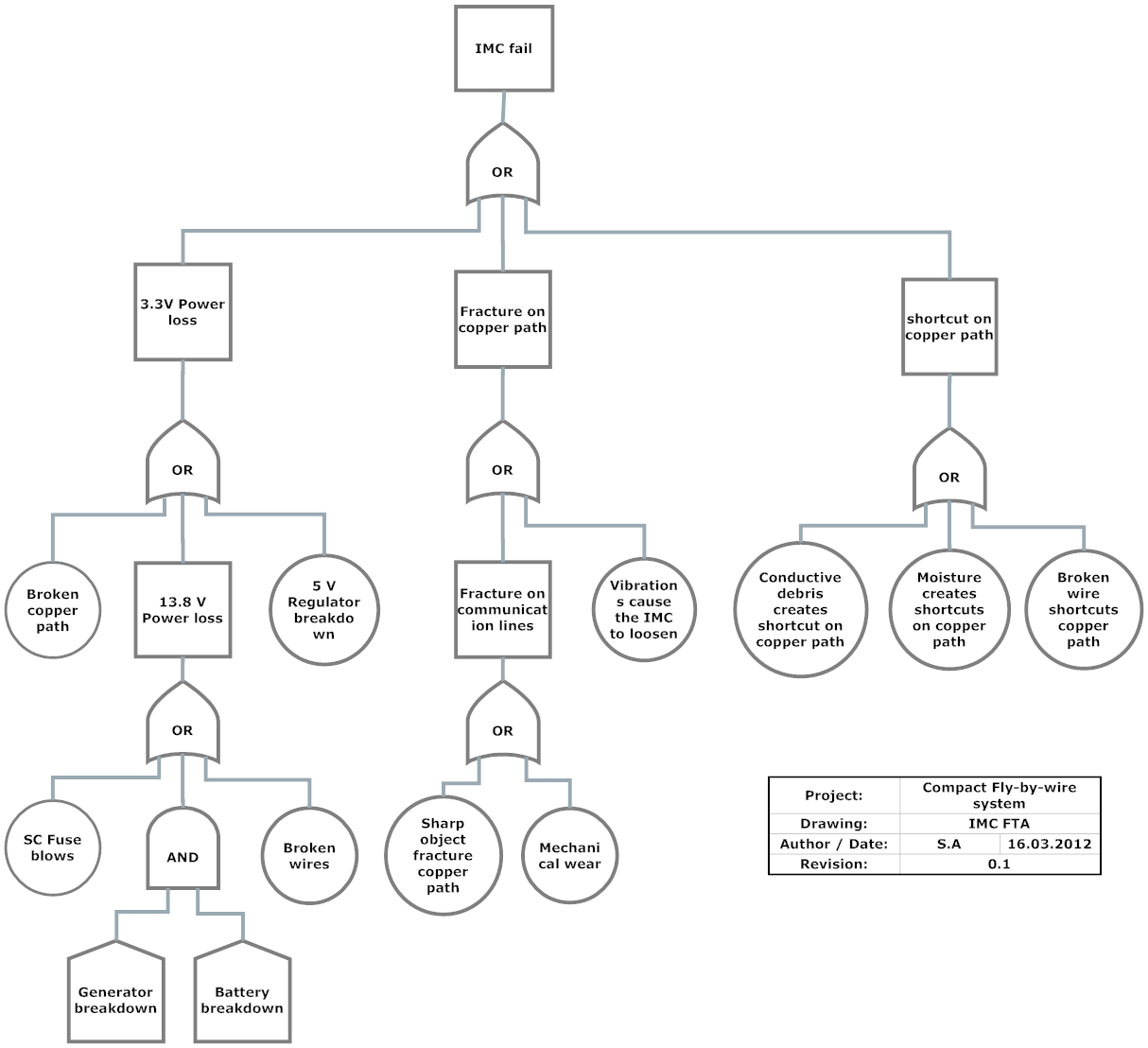
Fault tree diagram:



Part of	SC	
Description of the subsystem	The LPC1768 is the “heart” of the SC, and it does all the calculations and handle all I/O’s.	
Consequence of total failure:	If the LPC fails on the SC. All SC functions will stop working, the SC will stop sending a package to MCC2 and MCC2 will automatically be operational. (Ref: Software research, Chapter: State Failure Research) Simultaneously an alarm will be given and the SC light on the HMI panel will turn off or turn Red (depending on the fault reason). When SC is non-functional the pilot is the “Supervisor”. If something happens with the MCC in control (MCC2 or another MCC assigned by the pilot) The pilot has to change MCC manually. If the aircraft is controlled by the autopilot when the LPC fails. The autopilot will stop, MCC2 will take command and the pilot must fly the aircraft manually.	
MTBF:	20,485.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	3 hours	
Owner and date	A.G	19.04.2012

6.1.5. IMC

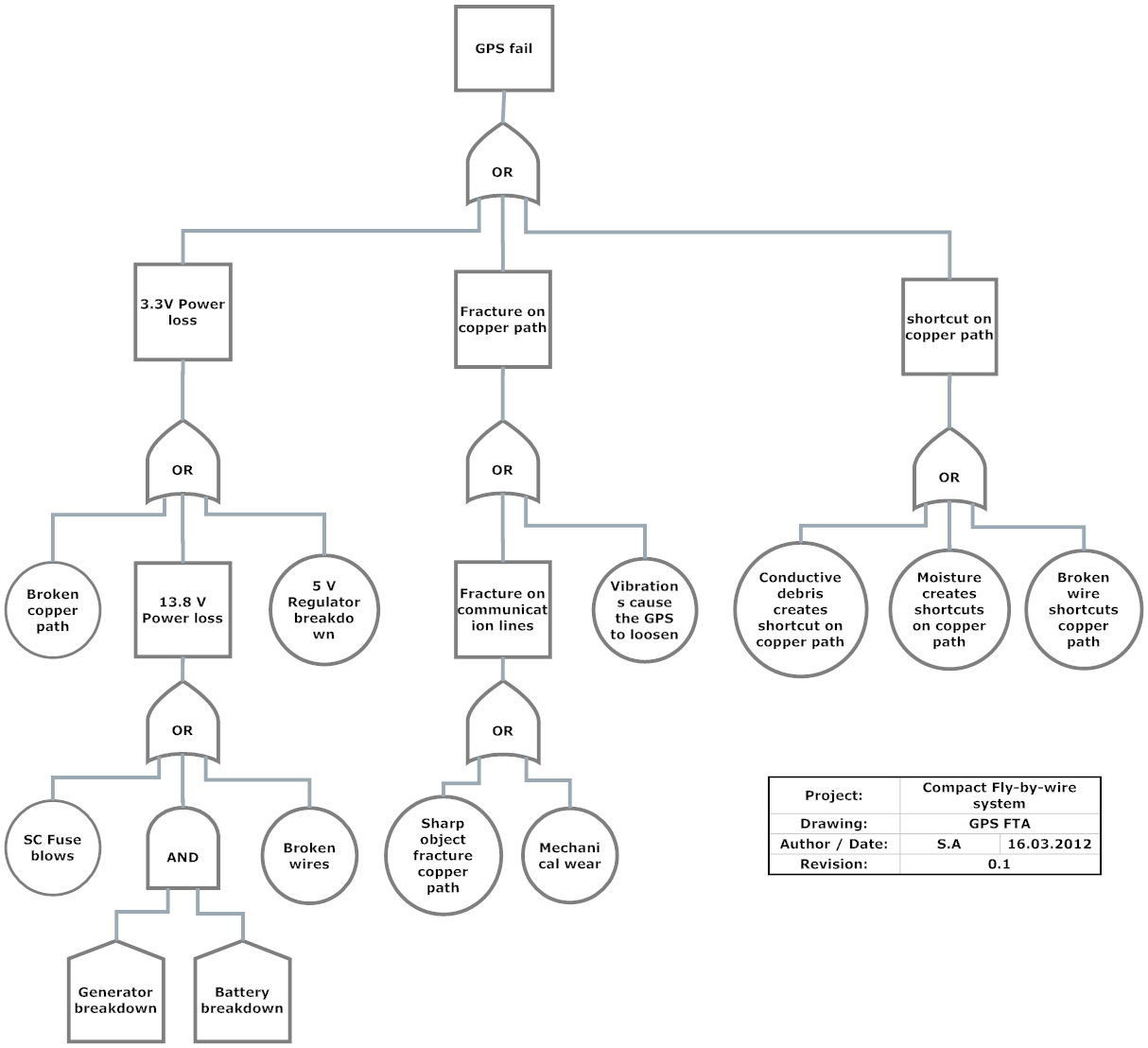
Fault tree diagram:



Part of	SC	
Description of the subsystem	IMC consists of three units; Gyro, Magnetometer and accelerometer. This will provide information about the flight to the SC.	
Consequence of total failure:	If the IMC fails, the SC will not have all the desirable functions, but it will still be able to automatically change MCC if something happens to it.	
MTBF:	36,464.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	19.04.2012

6.1.6. GPS

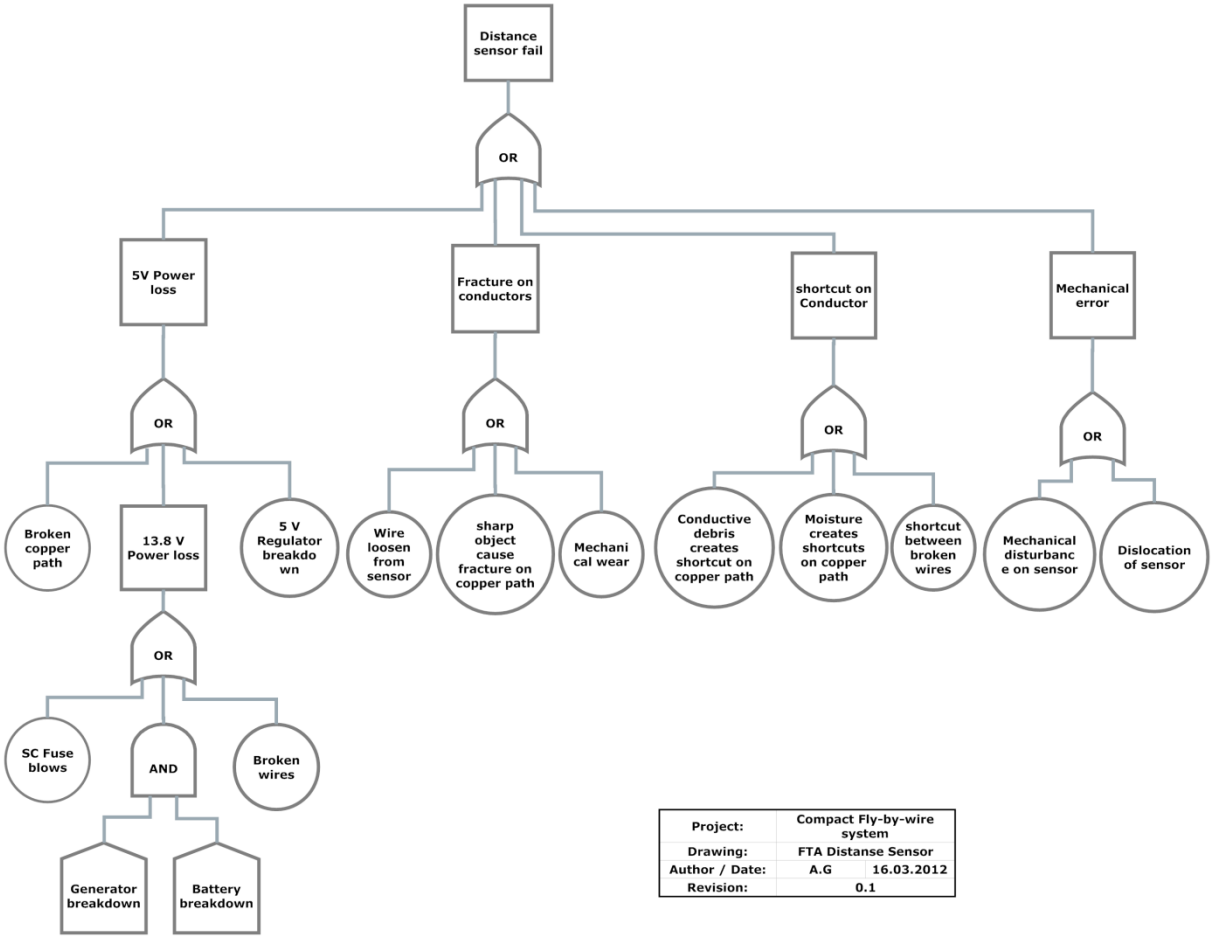
Fault tree diagram:



Part of	SC	
Description of the subsystem	The GPS are able to calculate the airplanes position through satellites.	
Consequence of total failure:	If the GPS fails, the autopilot will not be able to operate the airplane, but the SC will still be able to automatically change MCC if something happens to it and have all the other functions. The pilot will also not be able to get the airplanes position.	
MTBF:	29,449.0 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	19.04.2012

6.1.7. Distance sensor

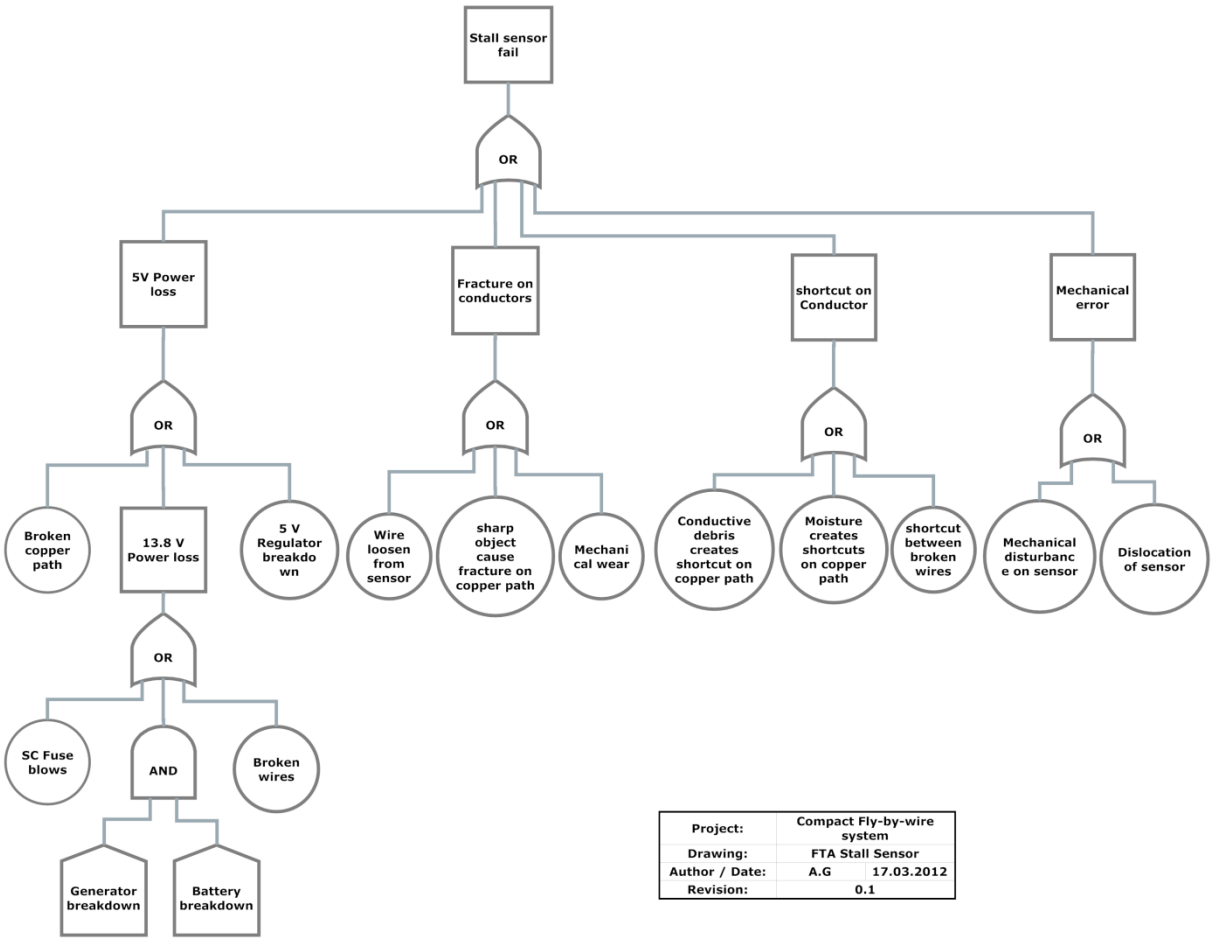
Fault tree diagram:



Part of	SC	
Description of the subsystem	The Distance sensor is used for takeoff and landing, to measure the exact distance to the runway/water. It has a short range, and is only used when the aircraft is close to the ground.	
Consequence of total failure:	If the Distance sensor fails, the pilot only has the GPS altitude and visual measurement to show the distance to the ground.	
MTBF:	28,365.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hours	
Owner and date	A.G	19.04.2012

6.1.8. Stall sensor

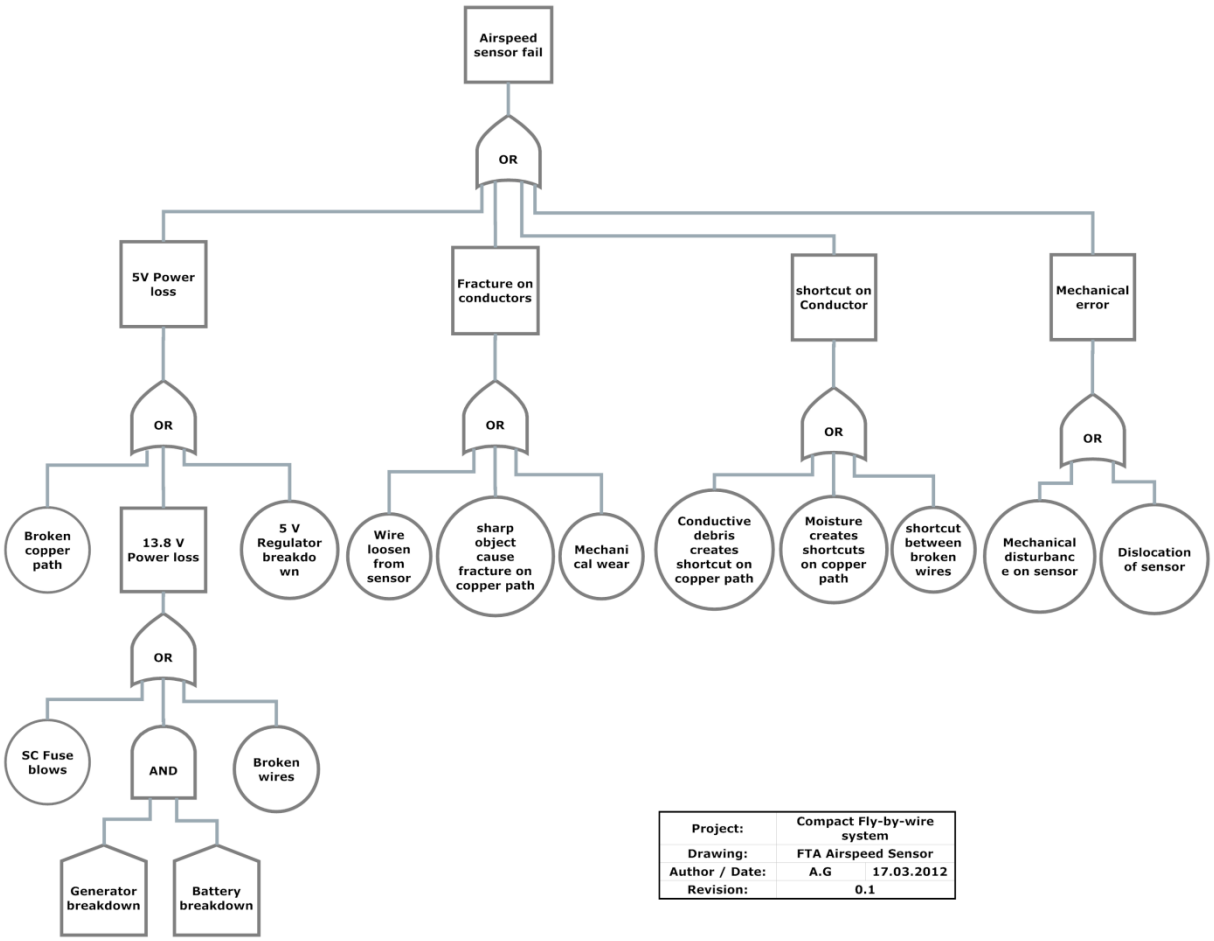
Fault tree diagram:



Part of	SC	
Description of the subsystem	The stall sensor measures the angle of attack of the airplane, and by knowing the stall limit of the airplane, the maximum angle of attack can be calculated and the system can prevent the aircraft ending up in stall or deep stall.	
Consequence of total failure:	If the stall sensor fails, the system will not be able to detect or prevent the aircraft from stalling. It is not a critical failure to the system function; however it is advisable to fix the problem as soon as possible of safety reasons.	
MTBF:	28,365.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	A.G	19.04.2012

6.1.9. Airspeed sensor

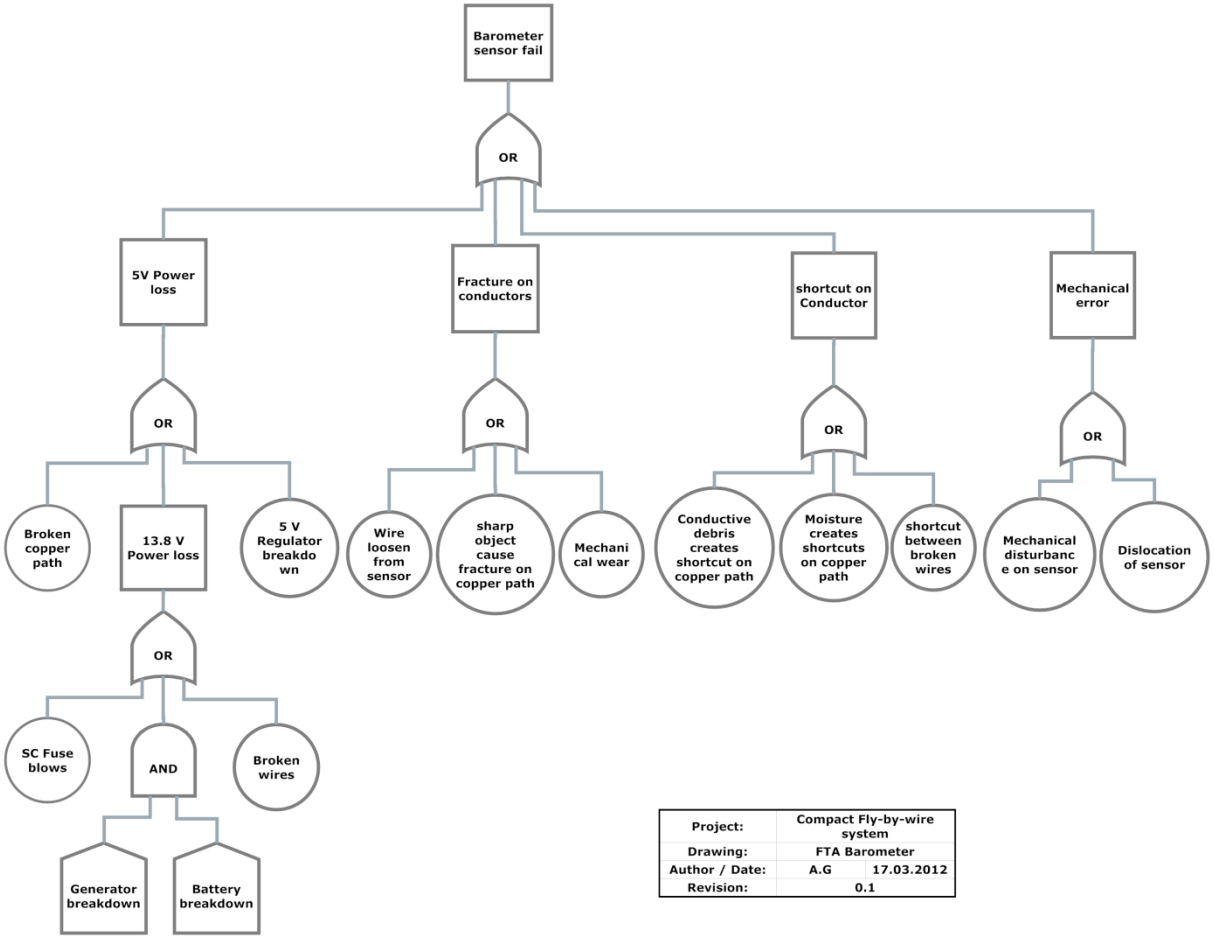
Fault tree diagram:



Part of	SC	
Description of the subsystem	The airspeed sensor measures the airflow around the aircraft, and therefore measures the airspeed of the airplane.	
Consequence of total failure:	If the airspeed sensor fails, it is not possible to measure the actual airspeed of the aircraft; However the GPS measures the ground speed, so the pilot has a certain indication of the speed. He will however not know for certain the amount of lift generated, since this is a result of the airspeed. All in all it is not a critical failure to the system, as long as the pilot is aware of it.	
MTBF:	28,365.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	A.G	19.04.2012

6.1.10. **Barometer**

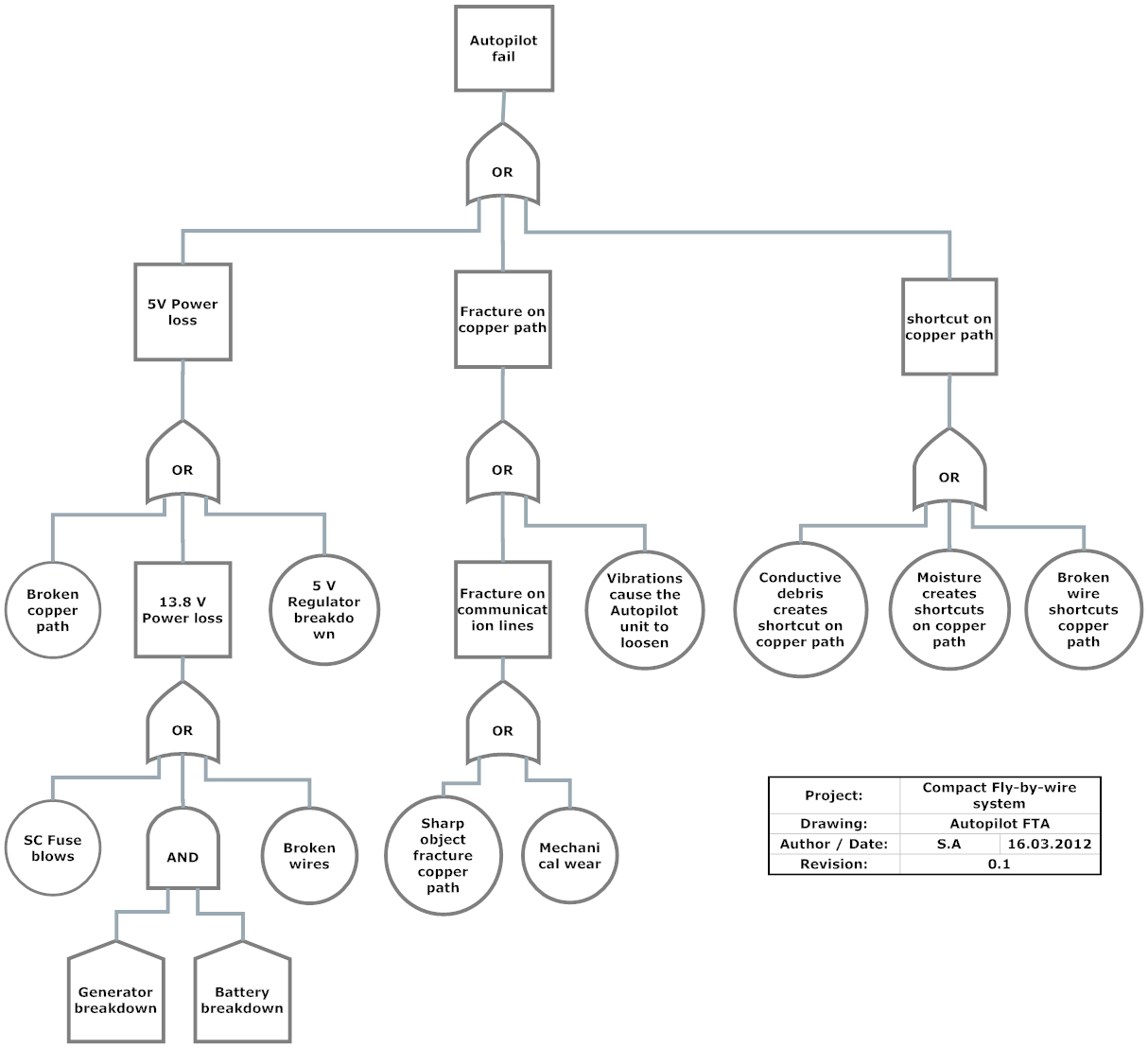
Fault tree diagram:



Part of	SC	
Description of the subsystem	The Barometer measures the atmospheric pressure around the aircraft, and if it is calculated it then gives a good estimate of the altitude of the aircraft. It must be calculated before every flight as a result of the atmospheric pressure changes that follows/gives the weather.	
Consequence of total failure:	If the barometer fails; you still have the GPS to measure the altitude, and the distance sensor to measure the distance from the ground at low altitudes. It is not a critical failure to the function of the system.	
MTBF:	28,365.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	2 hours	
Owner and date	A.G	19.04.2012

6.1.11. **Autopilot**

Fault tree diagram:

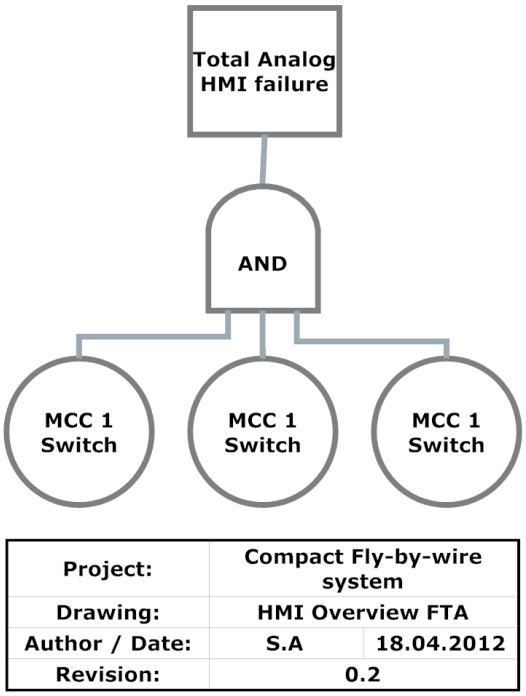


Part of	SC	
Description of the subsystem	The autopilot is able to operate the airplane through calculations and predetermined preferences.	
Consequence of total failure:	If the autopilot fails, the SC will not be able to operate the airplane through it, but it will still be able to automatically change MCC if something happens and have all the other functions.	
MTBF:	36,464.8 Hours between failures. Ref: Excel-diagram\SC Rev0.2.xlsx	
Time spent (Hours)	1 hour	
Owner and date	S.A	16.03.2012

7. HMI-PANEL

7.1.1. HMI FTA

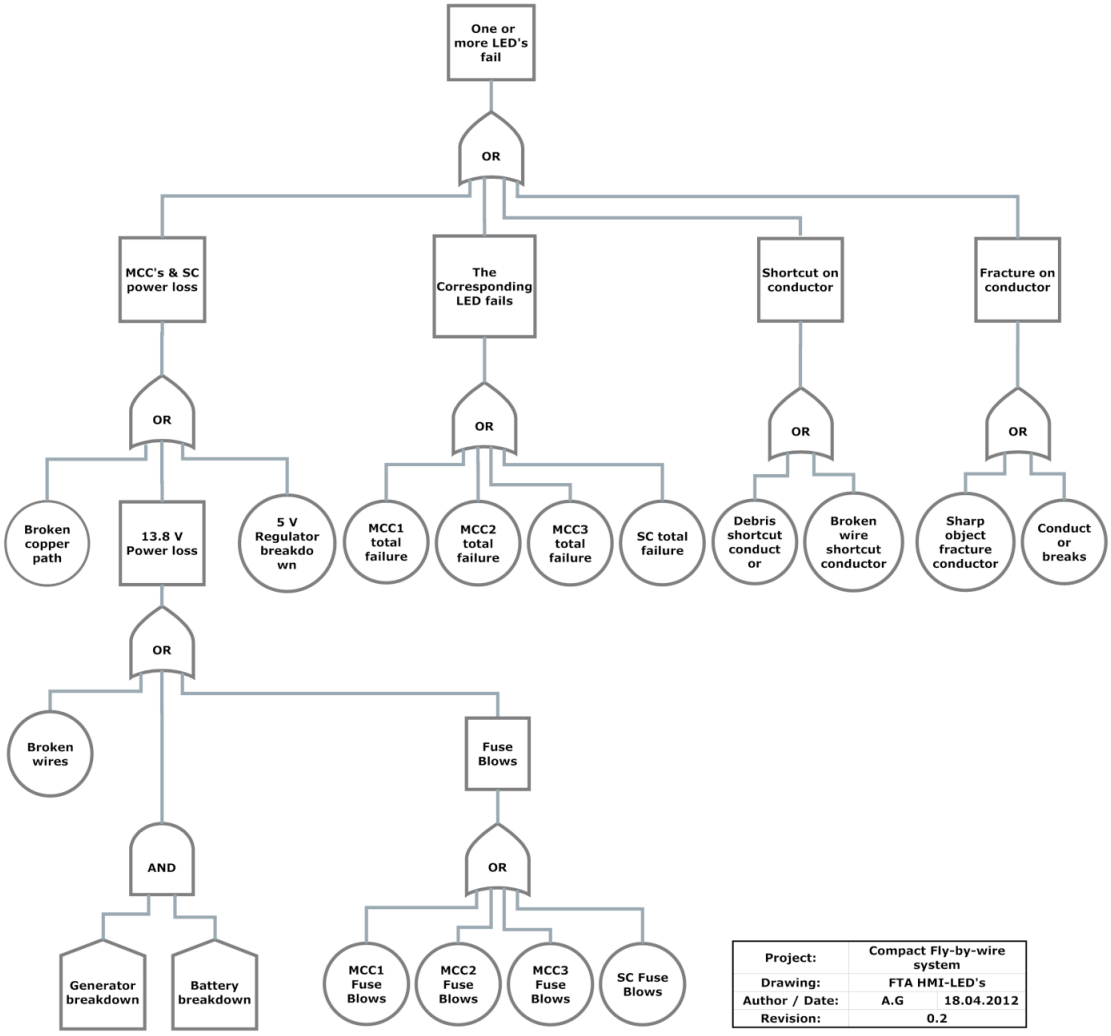
Fault tree diagram:



Part of	This is the FTA of the HMI.	
Description of the system	This is the entire HMI FTA system. The HMI panel consists of LEDs and switches indicating which MCC/SC who is running. These switches are override switches.	
Consequence of total failure:	Total failure of the HMI means that the airplane cannot be manually overridden by the pilot, and the SC/MCC2 is operative. This will not affect the maneuverability of the airplane. If the HMI, SC and MCC2 fails at the same time, the flight will be out of control. . If all of the three fails the pilot then has two choices: 1 try to control the aircraft using the trim tabs on the control planes. 2 pull the emergency parachute.	
MTBF:	3,734,944,338 hours between failures. Ref: Excel-diagram\HMI Rev0.1.xlsx The reason for the High MTBF is of the AND gate. All the Switches need to fail at the same time in order for the total analog HMI to fail.	
Time spent (Hours)	2 hours	
Owner and date	S.A / A.G	18.04.2012

7.1.2. HMI LED's

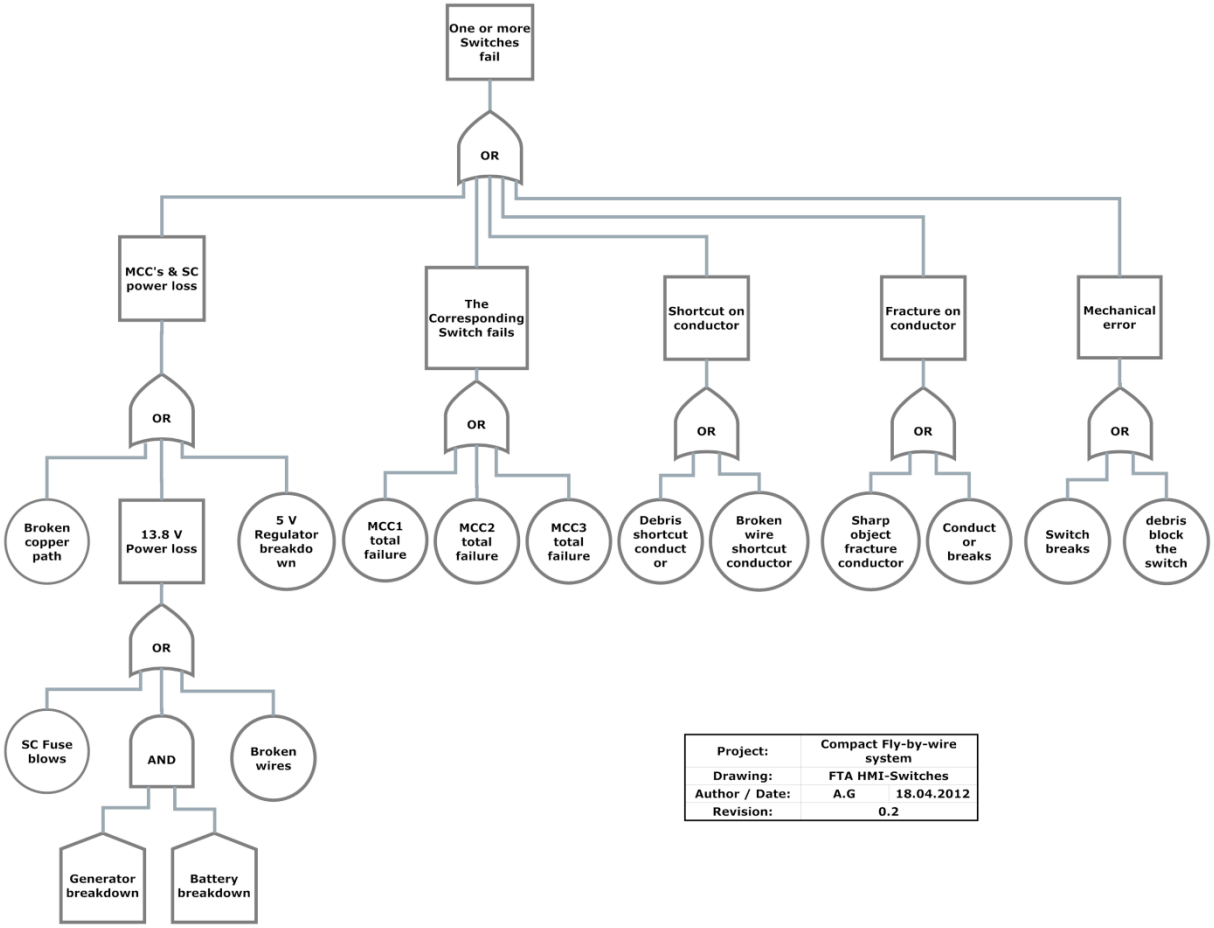
Fault tree diagram:



Part of	HMI-Panel	
Description of the subsystem	The HMI-LED's indicate the state of the corresponding MCC's or SC. The LED's can be tested using a lamp test button. Each LED is Powered by its respective MCC / SC.	
Consequence of total failure:	If the one or more LED's fail, it will not be a critical failure to the function of the system. However; if the SC is down along with the LED's the pilot will not know which of the MCC's to use. And he will think every MCC not having a working LED is down, and he is probably right. Therefore it is important of safety reasons that the LED's work at any given time.	
MTBF:	1,346.4 hours between failures. Ref: Excel-diagram\HMI Rev0.1.xlsx 1,346 hours seems like a short time, and it is. However this number does not represent the lifetime of the LED. It rather represent the time between each time the system fails to provide power for one or more LED's.	
Time spent (Hours)	3 hours	
Owner and date	A.G	19.04.2012

7.1.3. HMI-Switches

Fault tree diagram:



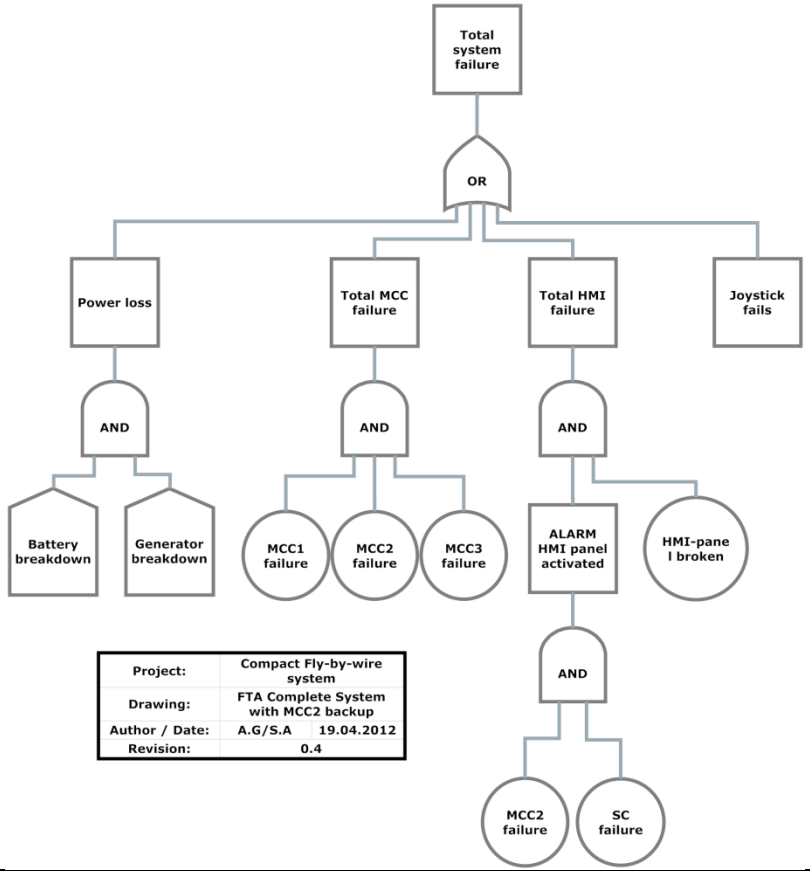
Part of	HMI-Panel	
Description of the subsystem	The Switches makes it possible for the pilot to manually switch between the MCC's. And it is a safety factor if the SC fails. Each Switch is powered by its respective MCC	
Consequence of total failure:	If the SC is out of order and the switches fail, it is a critical failure to the system. The pilot will not be able to switch MCC, if the operating MCC fails the consequence can be fatal; and the pilot has to options; try to control the aircraft using the trim tabs on the control surfaces, or pull the emergency parachute. This is however only the case if the SC, the operating MCC and the Switch fails at the same time.	
MTBF:	1,551.5 hours between faults. Ref: Excel-diagram\HMI Rev0.1.xlsx	
Time spent (Hours)	2 hours	
Owner and date	A.G	18.04.2012

8. COMPACT FLY-BY-WIRE SYSTEM

Here we integrate the results from the SC, MCC and HMI-Panel to form the complete system fault tree analysis.

8.1.1. FTA Complete system with MCC2 backup

Fault tree diagram:



Part of	This is the FTA of the entire system.	
Description of the system	This is the entire Compact fly-by-wire system. The system we are developing and in the end will control the aircraft. For further description of the function of the MCC2 in the Fault tree diagram above; Refer to: Software Research Chapter: State Failure Research. We did not add the Stepper Motor in this FTA calculation because the stepper motor is "outside" of our system, and it should therefore not affect our MTBF number. There is possible to use more than one stepper motor for redundancy.	
Consequence of total failure:	Total failure means that the whole system has failed; The Pilot then has two choices: 1 try to control the aircraft using the trim tabs on the control planes. 2 pull the emergency parachute.	
MTBF:	2,307,825 hours between failures. Ref Excel-diagram\Compact fly-by-wire system Rev.0.2.xlsx According to requirement: R310.1 the MTBF must exceed 800,000 hours. Our system meets this requirement by a good margin.	
Time spent (Hours)	4 hours	
Owner and date	A.G	19.04.2012

9. REFERENCES

Num.	Reference source	Description	Date
1	Fault-tree analysis.pdf	Referring to the design, of the FTA and how we compute the MTBF	20.03.2012
2	Rel_MTBF.pdf	Referring to how we compute the MTBF values	20.03.2012
4	Excel-diagram\Common Rev0.2.xlsx	The MTBF numbers for common units and components	19.04.2012
5	Excel-diagram\Compact fly-by-wire system Rev.0.2.xlsx	The MTBF numbers for the whole system	19.04.2012
6	Excel-diagram\HMI Rev0.1.xlsx	The MTBF numbers for the HMI panel	19.04.2012
7	Excel-diagram\MCC Rev0.3.xlsx	The MTBF numbers for the MCC	19.04.2012
8	Excel-diagram\SC Rev0.2.xlsx	The MTBF numbers for the SC	19.04.2012

10. REVISIONS

If any changes to the document are done, a new revision will be issued

Rev	Description	Date	Name
0.1	Made template	02.03.2012	A.G
0.2	Made: The MCC FTAs	12.03.2012	S.A / A.G
0.3	Changed: 5.1.6, **Error! Reference source not found.**, 4.1.2, Made a new roup of FTAs; Common units between SC and MCC.	14.03.2012	A.G / S.A
0.4	Reorganized all the FTA diagrams. Made: **Error! Reference source not ound.**	15.03.2012	A.G / S.A
0.5	Made: **Error! Reference source not found.**, **Error! Reference source t found.**, 5.1.7, 6.1.6, 6.1.5, 6.1.11, 5.1.1, **Error! Reference source not found.**	16.03.2012	A.G / S.A
0.6	Made: 6.1.8, 6.1.9, 6.1.10, 7.1.2, 7.1.3	17.03.2012	A.G
0.7	Made: 6.1.1, 7.1.1, 5.1.4,	19.03.2012	S.A
0.8	Listed References, made some comments to the chapters	20.03.2012	A.G
0.9	Updated: 6.1.4, 6.1.1, 5.1.3, 5.1.4, **Error! Reference source not found.**, REF _Ref322432307 \r \h 6.1.2, Deleted: 5.1.6 MUX	17.04.2012	A.G / S.A
0.10	Updated: 5.1.1, 5.1.2, 5.1.3, 5.1.6, 5.1.7, 7.1.1, 7.1.2, 7.1.3,	18.04.2012	A.G
0.11	Updated: 9 References 8.1.1, 7.1.2, 6.1.11, 6.1.10, 6.1.9, 6.1.8, 6.1.7, 6.1.6, 6.1.5, 6.1.4, 6.1.3, 6.1.2, 6.1.1, 5.1.4, 4.1.5, 4.1.4, 4.1.3, 4.1.2, 4.1.1 & 1.1 Explanation to the MTBF numbers,	19.04.2012	A.G
1.0	Made the public release. Made: 1.3, and checked the grammar	20.04.2012	A.G

Requirement & Test Specification

Bachelor Project

Compact Fly-by-wire System

Version	2
Category	Released
Issue Date	23.05.2012
Made by	A.G, O.R and R.L

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1. PURPOSE

The purpose of this document is to define the requirements for the system. And to define tests for all the requirements.
We have to be sure that the system works as supposed and that we get the expected output when we execute an input command. We have defined a test for each of the requirements, and the tests are numbered according to their respective requirement number.

The System output is the control surfaces shown in Fig.1. Inputs to the system are the pilot's joystick Fig. 2 and an IMU.

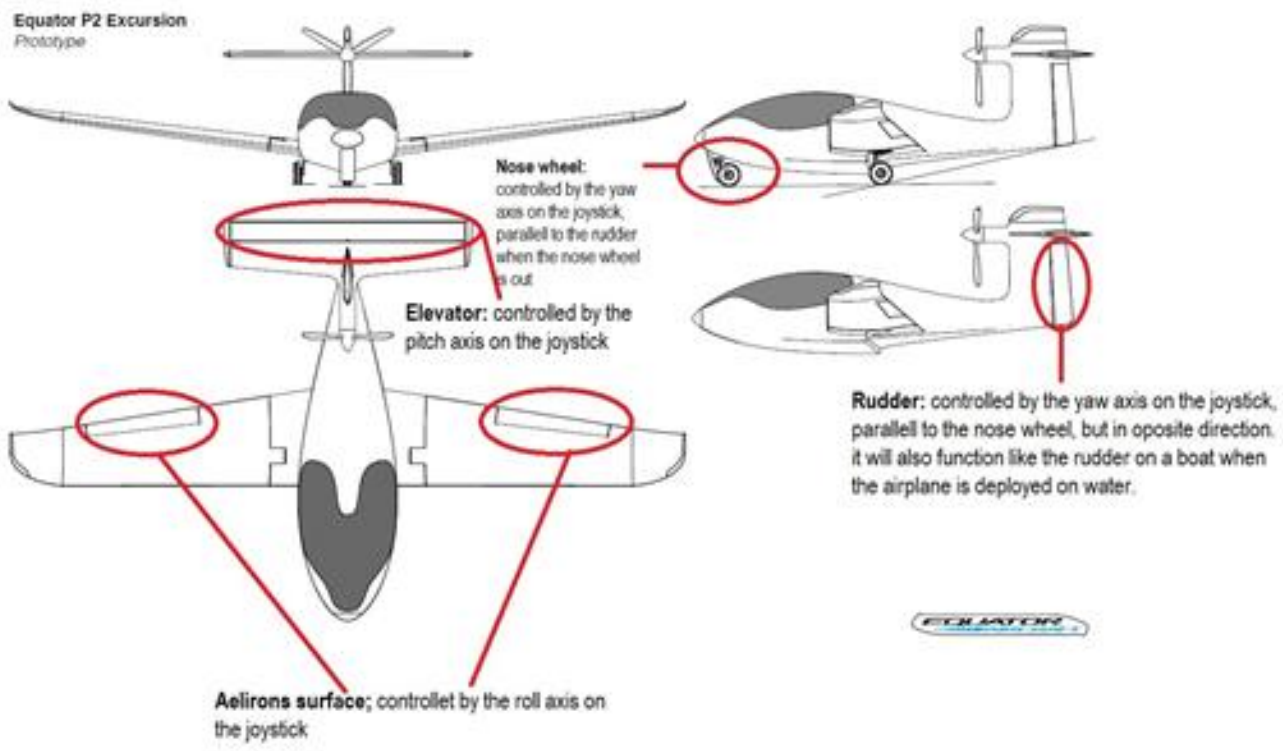
Equator P2 Excursion
Prototype
Nose wheel: controlled by the yaw axis on the joystick, parallell to the rudder when the nose wheel is out
Elevator: controlled by the pitch axis on the joystick
Rudder: controlled by the yaw axis on the joystick, parallell to the nose wheel, but in oposite direction. it will also function like the rudder on a boat when the airplane is deployed on water.
Aelirons surface; controllet by the roll axis on the joystick

Figure 1: Control Surfaces

Figure 2: Joystick

2. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser
IMC / IMU	Inertial Measurement Card; is an electronic device that measures and reports on the aircraft's orientation and gravitational forces using a combination of accelerometers and gyroscopes.
MTBF	Mean Time Between Failures
MCC	Main Controller Card
SC	Supervision Card

3. REFERENCES

Num.	Reference Document	Description	Date
[1]	Idea document	For definition of the project	03.01.2012
[2]	http://www.ipc.org/4.0_Knowledge/4.1_Standards/IPC-A-610E-redline-April-2010.pdf	For description of soldering standard IPC-A-610E	03.01. 2012
[3]	http://www.tronico.fi/OH6NT/docs/NMEA0183.pdf	For description of the NMEA 0183 protocol	03.01. 2012
[4]	ASTM F2245 -11	Standard specification for design and performance of a Light Sport Airplane	04.01.2012
[5]	SAE ARP5007A	Development Process-Aerospace Fly-By Wire Actuation system	04.01.2012
[6]	SAE AIR4253A	Description of Actuation systems for aircraft With Fly-By-Wire Flight Control Systems	04.01.2012

4. DEFINITIONS

Name	Description
Priority A	Requirements that are essential for the function of the system
Priority B	Requirements that will give extra functionality to the system such as; additional external inputs, preparations for indicators and displays etc. Also safety features such as stall inhibitor, landing gear specifications, modular design etc. Generally the requirements are essential for the system to be approved and put to production regarding safety and usability.
Priority C	Requirements that will give extra ordinary functionality to the system, such as software configured for GPS, Gyro, Autopilot and other functions that will give extensive usability to the system.

5. REQUIREMENTS & TEST SPECIFICATION

5.1. COMMENTS

When the project is due, the airplane is not finished for us to mount our system. Therefore, we will not be able to do a SAT on the system. Some of the requirements and tests in this document is for the final product, and are meant as guidelines for us. We will however not be able to test these fully or test them at all, when this is the case; it is commented in the Test description.

5.2. Environmental conditions

Req. Code	Priority	Description	Date	Owner
R102.4	A	Temperature range between -30C +70C	02.01.2012	O.R
R105.1	A	Humidity Relative Humidity 100% (condensation)	02.01.2012	A.G
R106.1	A	Maximum G-force 10G	02.01.2012	A.G
R107.2	A	Vibrations due to turbulence and running generator	12.01.2012	A.G

Table 1: Environmental condition requirements

5.3. Overall system function

Test Code	Req. Code	Pri	Description	Date	Owner
	R205.4	B	The weight of the control system must not exceed 1 kg minus the actuators	10.01.2012	A.G
T205.3			This is a B requirement in the sense that safety comes first. It is desirable to save as much weight as possible; however it is not going to be on expense of the safety of the system. The test is simply done by weighing the entire system with mounting equipment before it is mounted in the aircraft.	10.01.2012	A.G
	R207.2	A	When the landing gear is extended, the nose wheel actuator must be activated and controlled parallel to the rudder, but in opposite direction. (Hence the yaw axis on the joystick turns clockwise, the nose wheel will turn clockwise and the rudder will turn counter clockwise)	22.11.2011	A.G
T207.3			The landing gear will not yet be mounted on the aircraft, so this test will simply be to check that the outputs of the system are according to the requirement.	04.01.2012	A.G
	R216.4	A	Dual source Input voltage 13.8VDC ±4V	10.01.2012	O.R
T216.3			This test will have to be done by Equator Aircraft Norway when the hybrid system is mounted. The voltage source will be measured when the batteries are at full load from the electric engine, and when it is recharging with the generator. If the voltage varies less than ±4V from 13.8VDC the test is passed.	10.01.2012	R.L

	R218.2	B	When the landing gear is retracted, the nose wheel actuator is disabled	03.01.2012	A.G
T218.2			We will simulate an input signal from the “retracted landing gear sensor” and then try to send a command to the nose gear. If no command is given, the test is passed.	04.01.2012	R.L
	R219.2	B	When the “retract landing gear” command is given, the nose wheel will first go to zero position, and then be retracted.	03.01.2012	A.G
T219.2			Since we have to use a FAT, we will test this requirement by observing the actuator when the “retract landing gear” command is given to the system. If the actuator goes to “zero position” before the command to retract the landing gear is given, the test is passed.	04.01.2012	R.L
	R220.2	B	The system must be open for additional external input for positional data and heading references	03.01.2012	A.G
T220.2			In this test, we can simply test if the additional external inputs are able to receive the proper data.	04.01.2012	R.L
	R221.2	B	The system must be open for additional external inputs using NMEA 0183 [3] serial protocol	03.01.2012	A.G
T221.2			To test this, we have to connect the NMEA 0183 serial protocol to our system and see if the communication is according to the protocol.	04.01.2012	R.L
	R222.2	B	The system must be open for additional external inputs from gyro reference platform	03.01.2012	A.G
T222.2			In this test, we can simply test if the additional external inputs are able to receive the proper data.	04.01.2012	R.L
	R223.2	B	The system must be open for additional external input from Compass direction signal	03.01.2012	A.G
T223.1			To check this, we have to add an external compass and see that it corresponds with our system.	03.01.2012	R.L
	R224.2	B	The system must be open for additional external input from angle of attack sensor	03.01.2012	A.G
T224.2			We will here connect an external angle of attack sensor to our system and observe that the system receives the proper data.	04.01.2012	R.L
	R225.2	B	The system must be open for additional manual activation of autopilot (ON/OFF) (1x DI)	03.01.2012	A.G
T225.2			The activation is a simple ON/OFF switch, so here we have to check if the system is able to receive the Digital signal. And further give the command to the joystick “off” or give the command to the autopilot “on”.	04.01.2012	R.L
	R226.2	B	The system must be open for additional manual activation of gyro stabilization (ON/OFF) (1xDI)	03.01.2012	A.G
T226.2			The activation is a simple ON/OFF switch, so here we have to check if the system is able to receive the Digital signal. And further give the command to the joystick “off” or give the command to the gyro stabilization “on”.	04.01.2012	R.L

	R227.2	B	The system must be open for additional manual input of heading and climb input set point	03.01.2012	A.G
T227.3			Confirm that the heading and climb set point is received into the MCC software.	04.01.2012	R.L
	R228.2	B	The system must be prepared for LCD display	03.01.2012	A.G
T228.2			To check this requirement we have to connect a LCD display to our system, and confirm that it displays the right values.	04.01.2012	R.L
	R229.2	C	The system must be prepared for Tablet PC with Android operating system (USB serial communication)	03.01.2012	A.G
T229.2			To check this, we will try to connect a Tablet PC with android operating system to our system and see if they are communicating correctly.	04.01.2012	R.L
	R230.2	A	The system must be prepared for Digital status indicators	03.01.2012	A.G
T230.2			We connect some LED to our system and see if we can control them (ON/OFF).	04.01.2012	R.L
	R231.2	C	The system must be able to recharge the Tablet PC via the USB	03.01.2012	A.G
T231.2			To check this, we will see if the Tablet PC is recharging when it is connected to our system through the USB	04.01.2012	R.L
	R232.2	B	The weight of the actuating mechanism for each actuating point must not exceed 0.6kg	03.01.2012	A.G
T232.1			We have to weigh the actuating mechanism for each actuating point to check if they are below 0.6 kg	03.01.2012	R.L

5.4. Failure tolerance

Test Code	Req. Code	Pri	Description	Date	Owner
	R301.2	A	Manual override of critical control circuit choice	01.11.2011	K.M
T301.1			When the system is running, we will change the critical control circuit choice by the manual switch. We will have four choices, and for all the changes in circuit choice the system will change control circuit without lagging or losing data.	20.12.2011	A.G
	R302.3	A	Use dual modular redundancy	19.12.2011	A.G
T302.2			To test the dual modular redundancy, we will shut down the operating part of the system, to check if the second part will take over without losing too much data in the process.	20.12.2011	A.G
	R304.1	A	Ability to control surfaces in open loop	17.11.2011	O.R
T304.1			Confirm that control functions aren't disabled by removing feedback	05.01.2012	O.R
	R305.2	C	Failure probability must be supplied with each part, to establish the failure probability of the entire system.	03.01.2012	A.G
T305.1			This must be documented in the Fault Three Analysis	15.05.2012	A.G
	R306.1	A	Actuator electrical supply loss - The control plane must automatically go back to neutral position by aerodynamic forces	02.01.2012	A.G
T306.1			This test must be done when the stepper motor is mounted with the gearing.	15.05.2012	A.G
	R308.1	A	System condition status to be detected and displayed to pilot.	02.01.2012	A.G
T308.1			Confirm that the HMI-panel works, and that the respective LED's illustrate the condition of the respective MCC's / SC	15.05.2012	A.G
	R309.1	B	Modular design to comply with single/dual failure tolerance. And comply with MTBF requirements	03.01.2012	A.G
T309.1			Confirm that parts are easily replaceable and that it does not affect the MTBF	15.05.2012	A.G
	R310.1	A	The Mean Time Between Failure of the entire system must exceed 800,000 hours	19.04.2012	A.G
T310.1			Confirm this with the Fault Three Analysis	15.05.2012	A.G

5.5. Software

Test Code	Req. Code	Pri	Description	Date	Owner
	R401.2	A	Response time must be according to actuation and control surfaces requirements: R707, R710, R713, R718	03.01.2012	T.A
T401.2			Measure calculation time (should be less than 5ms)	03.01.2012	T.A

	R402.2	B	Software to be designed in modules for easy further development	03.01.2012	T.A
T402.2			Confirm modular development	03.01.2012	T.A
	R404.4	B	Access to system status on the SC	12.01.2012	O.R
T404.3			Update system status frequently to be sure that we have the correct system status	03.01.2012	O.R
	R405.3	C	Advanced function modules - Stall inhibit - Autopilot from gyro/compass platform - Autopilot from GPS reference	10.01.2012	O.R
T405.2			Confirm that that we can get data from these sensors and that we can get an output from simulating a change from these.	03.01.2012	O.R
	R407.3	C	Easy selection of control modes in flight	12.01.2012	O.R
T407.2			Confirm that we can change from autopilot to manual flight and don't lose any functionality		
	R408.1	B	Software development tools must be of high level language type with debugging and simulation facilities for fast development of code	03.01.2012	A.G
T408.1			Confirm that we have chosen a good development tool	03.01.2012	O.R
	R409.1	A	All program statements not self-explained to be commented	03.01.2012	A.G
T409.1			Confirm proper commenting	03.01.2012	O.R
	R410.1	B	Program versions to be managed by revisions and revisions history	03.01.2012	A.G
T410.1			Check that the programming history and revisions are correct.	10.01.2012	A.G
	R411.1	A	The prime function modules - Control planes actuation – rudder (water rudder) , elevator & ailerons - Nose gear actuation	03.01.2012	A.G
T411.1			Check that the output corresponds with the input	10.01.2012	A.G
	R412.2	A	Monitoring of supervisor control functions	10.01.2012	A.G
T412.1			Confirm that the supervisor control functions are enabled by exceeding the limits set by the supervisor, and confirm that the status is updated	10.01.2012	A.G
	R413.1	B	Receive and store data from the IMC on the SC	10.01.2012	O.R
T413.1			Confirm that the data is received and stored on the SC	12.01.2012	A.G
	R414.2	A	The SC is monitoring the selection of MCC	12.01.2012	A.G
T414.1			Confirm that the operating MCC is monitored by the SC	12.01.2012	A.G
	R415.2	A	Display the selection of MCC to the pilot	12.01.2012	A.G
T415.1			Confirm that the operating MCC is displayed to the pilot	12.01.2012	A.G
	R416.1	A	Display the status of the MCC's to the pilot; "Not working", "standby" and "operating"	12.01.2012	A.G
T416.1			Confirm that the status of the MCC's is displayed to the pilot	12.01.2012	A.G

5.6. Hardware

Test Code	Req. Code	Pri	Description	Date	Owner
	R501.3	C	Ability to mount the MCC on different locations to avoid common environmental impact	03.01.2012	O.R
T501.4			Confirm that the circuit boards can communicate over a distance (<4m)	12.01.2012	O.R
	R502.2	B	Module based HW for further development	03.01.2012	O.R
T502.2			Confirm modular development	03.01.2012	O.R
	R504.2	B	The soldering on the circuit board is according to the IPC-A-610E [2] standard	03.01.2012	A.G
T504.2			Document soldering	03.01.2012	O.R
	R505.3	C	The parts must tolerate the vibrations defined in R107	10.01.2012	A.G
T505.2			Confirm that the parts can withstand the vibrations	03.01.2012	O.R
	R506.3	C	Cables and the general equipment must be mounted with spring loaded connections and cable ties to avoid resonance vibrations.	10.01.2012	A.G
T506.3			Cannot be tested in FAT. However it will be checked and confirmed during the installation in the aircraft	12.01.2012	O.R
	R509.1	A	The MCC must contain a complete and independent function as described in the software (8.4), failure tolerance (8.3) and the system function (8.2) requirements.	03.01.2012	A.G
T509.1			Confirm that the MCC can execute all critical functions independently	03.01.2012	O.R
	R510.1	B	The MCC may be doubled or tripled if the failure tolerance analyses show an unacceptable failure risk.	03.01.2012	A.G
T510.1			Confirm that the MTBF goal is achieved by using the needed number of MCC’s	03.01.2012	O.R
	R511.1	A	The MCC is prepared for interface with the SC	03.01.2012	A.G
T511.2			Confirm communication between the two cards	12.01.2012	O.R
	R512.1	A	All the MCC’s not in use will be in active-stand-by mode	03.01.2012	A.G
T512.1			Confirm that the MCC’s not in use receive and calculate data by debugging interface	03.01.2012	O.R
	R513.1	A	The operating MCC can be chosen manually by the pilot	03.01.2012	A.G
T513.2			Confirm that the chosen MCC becomes active when chosen	12.01.2012	O.R
	R518.2	C	SC to be designed for the described signal interface, (ref. Software(8.4) and System function(8.2)) with 20% reserved capacity on I/O’s for further development	12.01.2012	A.G
T518.1			Check that the number of interfaces is according to requirements in Software (8.4), System functions (8.2) and R518.	05.01.2012	O.R
	R519.1	B	The circuit boards to be of multi layer design with surface mounted components	03.01.2012	A.G
T519.1			Confirm that the circuit is of multi layer design and has surface mounted components	05.01.2012	O.R

5.7. Joystick

5.7.1. Important notes to the requirements:

The Joystick is going to be designed by our contractor. Requirement's R602, R603, R606, R607 and R610 are all set by our contractor to give us an image of how the joystick will work. R611 is a requirement we set for our contractor to make the joystick compatible with our system.

Test Code	Req. Code	Pri	Description	Date	Owner
	R601.1	A	The yaw axis on the joystick (twisting movement) will replace the pedals to control the rudder, when the joystick is twisted clockwise, the rudder will rotate anticlockwise and vice versa.	02.01.2012	A.G
T601.1			Control that output is according to input	03.01.2012	O.R
	R612.1	A	The yaw axis on the joystick control the nose gear when it is extended	02.01.2012	A.G
T612.1			Control that the nose wheel stepper motor is controlled by the yaw axis	03.01.2012	O.R
	R602.2	C	Joystick rotating angle (yaw axis): ±25˚ from zero position (forward direction)	03.01.2012	A.G
T602.2			Control that the joystick can twist ±25˚ in the yaw axis	03.01.2012	O.R
	R603.2	C	Joystick rotating torque (yaw): 100-300g/cm from zero to max position in each direction	03.01.2012	A.G
T603.2			Confirm that the joystick torque is within the given range	03.01.2012	O.R
	R604.1	A	The forward and backward movement on the joystick (pitch) control the elevator	02.01.2012	A.G
T604.1			Control that output is as expected	03.01.2012	T.A
	R605.1	A	Backward movement move the elevator upwards and vice versa	02.01.2012	A.G
T605.1			Control that output is as expected	03.01.2012	O.R
	R606.2	C	Joystick movement angle (pitch axis): ±25˚ from zero position (forward direction)	03.01.2012	A.G
T606.2			Control that the joystick can twist ±25˚ in the pitch axis	03.01.2012	T.A
	R607.2	C	Joystick movement torque (pitch and roll): 100-500g/cm from zero to max in each direction for pitch and roll	03.01.2012	A.G
T607.2			Confirm that the joystick torque is within the given range	03.01.2012	O.R
	R608.1	A	The sideways movement on the joystick (roll) control the ailerons	02.01.2012	A.G
T608.1			Control that output is as expected	03.01.2012	T.A
	R609.1	A	Left "roll" movement on the joystick move the left aileron upwards and the right aileron downwards and vice versa	02.01.2012	A.G
T609.1			Control that output is as expected	03.01.2012	O.R

	R610.2	C	Joystick movement angle (roll axis): ±25˚ from zero position	03.01.2012	A.G
T610.2			Control that the joystick can twist ±25˚ in the roll axis	03.01.2012	T.A
	R611.3	B	Redundancy output signals from joystick	27.01.2012	K.M
T611.4			Confirm the redundancy (two or more outputs from joystick per axis)	27.01.2012	O.R

5.8. Control surface

Test Code	Req. Code	Pri	Description	Date	Owner
	R702.1	A	The rudder must be able to move 25 degrees in both directions from zero position. Zero position is when the rudder is parallel to the vertical stabilizer.	02.01.2012	A.G
T702.1			Control that output is as expected	03.01.2012	O.R
	R703.1	A	The elevator must be able to move 25 degrees in both directions from zero position. Zero position is when the elevator is parallel to the tail plane.	02.01.2012	A.G
T703.1			Control that output is as expected	03.01.2012	O.R
	R704.1	A	The ailerons must be able to move 25 degrees in both directions from zero position. Zero position is when the ailerons are parallel to the wing.	02.01.2012	A.G
T704.1			Control that output is as expected	03.01.2012	O.R
	R706.2	C	Aileron torque is minimum 40kg/cm in both directions	27.01.2012	A.G
T706.2			Confirm that the ailerons can withstand 40kg/cm	27.01.2012	O.R
	R707.2	B	Aileron response time from zero to maximum deflection (25˚) in each direction: 0.5 sec	03.01.2012	A.G
T707.2			Confirm that they have the specified angular velocity	03.01.2012	T.A
	R708.1	A	Minimum resolution of aileron surfaces: 5 steps/degree	02.01.2012	A.G
T708.1			Confirm the resolution	03.01.2012	T.A
	R709.2	C	Rudder torque is minimum 40kg/cm in both directions	27.01.2012	A.G
T709.2			Confirm that the rudder can withstand 40kg/cm	27.01.2012	T.A
	R710.2	B	Rudder response time from zero to maximum deflection (25˚) in each direction: 0.5 sec	03.01.2012	A.G
T710.2			Confirm that they have the specified angular velocity	03.01.2012	T.A
	R711.1	A	Minimum resolution of rudder surface: 5 steps/degree	02.01.2012	A.G
T711.1			Confirm the resolution	03.01.2012	T.A
	R712.2	C	Elevator torque is minimum 40kg/cm in both directions	27.01.2012	A.G
T712.2			Confirm that the elevator can withstand 40kg/cm	27.01.2012	T.A

	R713.2	B	Elevator response time from zero to maximum deflection (25˚) in each direction: 0.5 sec	03.01.2012	A.G
T713.2			Confirm that they have the specified angular velocity	03.01.2012	T.A
	R714.1	A	Minimum resolution of elevator surface: 5 steps/degree	02.01.2012	A.G
T714.1			Confirm the resolution	03.01.2012	T.A
	R716.2	C	Nose gear torque is minimum 40kg/cm	27.01.2012	A.G
T716.2			Confirm that the nose gear can withstand 40kg/cm	27.01.2012	A.G
	R717.1	A	Nose gear movement ±90˚ from forward heading	02.01.2012	A.G
T717.1			Confirm that nose gear has ±90˚ movement	05.01.2012	T.A
	R718.2	A	Nose gear response time from zero to max deflection: maximum 8sec	03.01.2012	A.G
T718.2			Confirm that they have the specified angular velocity	03.01.2012	O.R
	R719.2	C	Minimum resolution of nose gear: 1 steps/degree	27.01.2012	A.G
T719.1			Confirm that the resolution of the nose gear is more than 1 step/degree	27.01.2012	A.G

6. RESPONSIBILITY

Axel Gravningsbraaten is responsible for updating and controlling the requirements in this document and Ole A. Riiser is responsible for updating and controlling the Tests.

Key Person	Summary of Responsibilities within this Procedure
Axel Gravningsbraaten	Responsible for the requirements
Ole A. Riiser	Responsible for the Tests

7. REVISIONS

Rev	Description	Date	Name
0.1	Filled in requirement list.	16.12.2011	O.R
0.2	Made test req: T201, T202, T205, T207, T208, T209, T210, T211, T212, T213, T214, T507, T302. Updated req list to rev 0.6. and updated table 2.2, 2.3 and 2.4	19.12.2011	A.G
0.3	Updated T205, T208, T209, T210, T211, T212, T213, T214, T302. Made T301, T204, T501, T503, T504, T505, T506, T507, T508, T503.	20.12.2011	A.G
0.4	Made test for Joystick, control surfaces and software	03.01.2012	T.A, O.R
0.5	Uptaded T207 Made T216, T217, T218, T219, T220, T221, T222, T223, T224, T225, T226, T227, T228, T229, T230, T231, T232	03.01.2012	R.L
0.6	Made some cosmetic changes to all tables, put in References, Updatet: T207, T216, T217, T218, T219, T220, T221, T222, T224, T225, T226, T227, T228, T229, T230, T231	04.01.2012	A.G,K.M
0.7	Updating the Responsibility (3)	05.01.2012	A.G
0.8	Deleted R303, grammar correction	05.01.2012	T.A
1.0	Released Document	6.1.2012	O.R
1.1	Abbreviation list. WSC->SC, IMU->IMC. Definitions (6): Priority B & C Updated: R205 & T205, R216 & T216, R405 Added: R410-R413 & T410-T413,	10.01.2012	A.G
1.2	Updated: T413-T415, R413-R415, R407, T501, R505, R506 & T506, T507, T508, T511, T513, T514, T516, R518, T611 Made: T416, R416 Deleted: R503 & T503, R515 & T515, R701 & T701,	12.01.2012	A.G
1.3	Deleted: R507 & T507, R508 & T508, R514 & T514, R516 & T516, R517 & T517 Updated: R611 & T611, R706 & T706, R709 & T709, R712 & T712, R716 & T716 Filled in: R719 Made: T719 Updated the abbreviation list (IMC)	27.01.2012	A.G
1.4	Updated: R205, R305.2 & T305.1, R306.1 & T306.1, R308.1 & T308.1, R309.1 & T309.1, R310.1 & T310.1 Deleted: R217 & T217	15.05.2012	A.G
1.5	Small updates and adjustments on the text.	19.05.2012	A.G
2	Made the official revision	22.05.2012	A.G

Test Results

Bachelor Project

Compact Fly-by-wire System

Version	1.0
Category	Released
Issue Date	29.05.2012
Made by	A.G, O.R
Checked by	K.M
Approved by	A.G

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1. SCOPE

The scope of this document is to describe the result of the requirement tests.

2. RESULT DESCRIPTION

Technical Term	Standard Definition
N/T	Not Tested, due to the lack of ability to do an SAT.
Passed	The test was successful and the system passed the test
Failed	The test was successful, but the system failed the test

3. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser
IMC / IMU	Inertial Measurement Card; is an electronic device that measures and reports on the aircraft's orientation and gravitational forces using a combination of accelerometers and gyroscopes.
MTBF	Mean Time Between Failures
MCC	Main Controller Card
SC	Supervision Card

4. TESTS TO THE REQUIREMENTS

4.1. Environmental conditions

The system we came up with is a proof of concept, not a complete system ready for production. And some of the work on the product is therefore not done professionally, (e.g soldering & mounting) this means that we have prioritized the function of the system, not the durability of it. The environmental conditions are therefore not tested.

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R102.4	A	N/T	We do not have enough time to test this requirement	15.05.2012	A.G
R105.1	A	N/T	We do not have enough time to test this requirement	15.05.2012	A.G
R106.1	A	N/T	We do not have enough time to test this requirement	15.05.2012	A.G
R107.2	A	N/T	We do not have enough time to test this requirement	15.05.2012	A.G

4.2. Overall system function

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R205.4	B	Passed	The circuit boards and, sensors and connectors weigh less than 1 kg. Though the weight of the entire system depends on the length of the cables between the cards	23.05.2012	A.G
R207.2	A	Passed	The output is according to the requirement	16.05.2012	A.G
R216.4	A	N/T	Test must be done by Equator Aircraft Norway	15.05.2012	A.G
R218.2	B	N/T	We have not been able to test this requirement due to shortage of time. It has been a low priority to do tests on the nose wheel.	29.05.2012	A.G
R219.2	B	N/T	This has to be tested when the landing gear is mounted on the prototype. The reason for this is that EAN will test if it goes back to zero position by aerodynamic forces	29.05.2012	A.G
R220.2	B	Passed	We have implemented this function on the SC PCB card, it is therefore now internal. The SC also has additional spare connectors for reference signals.	15.05.2012	A.G

R221.2	B	Passed	We have implemented this function on the SC PCB card, it is therefore now internal. The SC also has additional spare connectors for reference signals.	15.05.2012	A.G
R222.2	B	Passed	We have implemented this function on the SC PCB card, it is therefore now internal. The SC also has additional spare connectors for reference signals.	15.05.2012	A.G
R223.2	B	Passed	We have implemented this function on the SC PCB card, it is therefore now internal. The SC also has additional spare connectors for reference signals.	15.05.2012	A.G
R224.2	B	Passed	There is a spare AI terminal on SC for the angle of attack sensor.	19.05.2012	A.G
R225.2	B	Passed	SC is set up with a port handling the manual activation of the autopilot	15.05.2012	A.G
R226.2	B	Passed	SC is set up with a port handling the manual activation of the gyro stabilization	15.05.2012	A.G
R227.2	B	Passed	The SC does have climb rate (2xDI), heading set point (2xDI) and an altitude set point (2xDI) implemented for the autopilot. The SC does all the calculations and sends out a control signal directly to the stepper controller on the operating MCC.	15.05.2012	A.G
R228.2	B	Passed	With regards to the hardware the SC is ready for communication with an Android Tablet, which can be used as a display. The SC also has spare connectors which can be used for the LCD display for the autopilot.	15.05.2012	A.G
R229.2	C	Passed	With regards to the hardware, the SC is ready for an Android tablet.	15.05.2012	A.G
R230.2	A	Passed	Both the MCC's and the SC has spare DO connectors. In addition a green and a red LED are connected on the HMI panel for both SC and all the MCC's, to indicate the status of the cards.	15.05.2012	A.G
R231.2	C	Passed	The USB is standardized, and can charge at 5V	15.05.2012	A.G
R232.2	B	Passed	The weight of one stepper motor is less than 300grams. The weight of the rest of the mechanism depends on Equator Aircraft Norway.	15.05.2012	A.G

4.3. Failure tolerance

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R301.2	A	Passed	This is tested and it works, we however only use three choices, one for each MCC	23.05.2012	A.G
R302.3	A	Passed	We use triple modular redundancy instead of double.	23.05.2012	A.G
R304.1	A	Passed	We tested the stepper motors without any feedback. During the test no steps were skipped.	15.05.2012	A.G
R305.2	C	Passed	Ref. Fault Three Analysis	15.05.2012	A.G
R306.1	A	Passed	The stepper motors loose all retaining power when no power is connected, The control plane will therefore run freely if the power supply is lost. This must however be tested when the system is mounted by Equator Aircraft Norway.	15.05.2012	A.G
R308.1	A	Passed	Each MCC can control it's two HMI LEDs to show the correct status to the pilot	21.05.2012	O.R
R309.1	B	Passed	The failure tolerance and MTBF numbers are described in the Fault Three Analysis	15.05.2012	A.G
R310.1	A	Passed	Ref. Fault Three Analysis	15.05.2012	A.G

4.4. Software

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R401.2	A	N/T	We are not able to test this requirement with our test bench. The test must be done by Equator Aircraft Norway	23.05.2012	A.G
R402.2	B	Passed	Software is divided up in classes with a logical grouping. This ensures a easy readable code and possibilities for further developing	22.05.2012	K.M
R404.4	B	Passed	MCC can send information to SC and SC can read and process it.	22.05.2012	K.M
R405.3	C	N/T	We have not written any software for testing these functions.	22.05.2012	K.M
R407.3	C	Passed	Control modes can be set through SC and is done automatically. The system is also setup for development of autopilot.	22.05.2012	K.M
R408.1	B	Passed	The software we use for developing provides plenty of opportunities to further develop our system.	22.05.2012	K.M
R409.1	A	Passed	Commenting explains the coding and makes it easy readable.	22.05.2012	K.M

R410.1	B	Passed	We have made backup when there has been significant changes in the code. This works as our version history.	22.05.2012	K.M
R411.1	A	Passed	Moving the joystick moves the correct control surface.	22.05.2012	K.M
R412.2	A	N/T	This has to to with stall angle, and this sensor is not mounted on our system, the system is however ready for it.	23.05.2012	A.G
R413.1	B	Passed	This function has not been written due to a lack of time.	22.05.2012	K.M
R414.2	A	Passed	SC can receive data continuously or by asking for data. This makes it possible for SC to monitor the MCC's.	22.05.2012	K.M
R415.2	A	Passed	The working MCCs are displayed to the pilot through the HMI LEDs. This information can also be displayed through the tablet when the software for it get's developed.	22.05.2012	K.M
R416.1	A	Passed	The status of the MCC is displayed through the HMI LEDs.	22.05.2012	K.M

4.5. Hardware

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R501.3	C	Passed	There is Three MCC's, they can be mounted anywhere in the airplane where it is desirable and with our current baud rate of 9600 distances of up to 4 meters is no issue.	15.05.2012	A.G
R502.2	B	Passed	The Microcontrollers (PIC18f8520 & LPC1768) are mounted with piggyback, and are therefore easily replaceable. The stepper controllers are modules soldered on the MCC's. The GPS and the IMC are also modules that are soldered on the SC. This makes them easily replaceable.	15.05.2012	A.G
R504.2	B	Failed	Due to the limited time, we had to do the soldering ourselves.	15.05.2012	A.G
R505.3	C	N/T	Due to limited time, we do not have time to test this requirement	15.05.2012	A.G
R506.3	C	N/T	Equator Aircraft Norway have to make sure the mounting is correct	15.05.2012	A.G
R509.1	A	Passed	The MCC's function independent as described.	15.05.2012	A.G
R510.1	B	Passed	Three MCC's is sufficient according to the Fault Three Analysis.	15.05.2012	A.G
R511.1	A	Passed	The MCC and the SC are prepared for interface.	15.05.2012	A.G

R512.1	A	Passed	By disabling the stepper controllers on the MCC in standby mode, they are able to do all calculations and operate as normal without sending commands to the motors.	15.05.2012	A.G
R513.1	A	Passed	The HMI panel is working, and the MCCs can be chosen manually.	29.05.2012	A.G
R518.2	C	Passed	The SC does have all required interface, with more than 30% reserve capacity on I/O's.	15.05.2012	A.G
R519.1	B	Passed	All PCB's are two layered. But with as few surface mounted components as possible, for better vibration resistance.	15.05.2012	A.G

4.6. Joystick

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R601.1	A	Passed	The output is according to the requirement	16.05.2012	A.G
R612.1	A	Passed	The output is according to the requirement	16.05.2012	A.G
R602.2	C	Passed/ N/T	The joystick we use for testing can twist ±90˚ , Equator Aircraft Norway must make sure the joystick to be used is according to the requirements	16.05.2012	A.G
R603.2	C	N/T	We do not have access to the actual joystick, it is not yet produced. Equator Aircraft Norway must make sure the joystick is according to requirement	16.05.2012	A.G
R604.1	A	Passed	The pitch axis controls the elevator stepper motor.	16.05.2012	A.G
R605.1	A	Passed	The output is according to the requirement	16.05.2012	A.G
R606.2	C	N/T	We do not have access to the actual joystick, it is not yet produced. Equator Aircraft Norway must make sure the joystick is according to requirement	16.05.2012	A.G
R607.2	C	N/T	We do not have access to the actual joystick, it is not yet produced. Equator Aircraft Norway must make sure the joystick is according to requirement	16.05.2012	A.G
R608.1	A	Passed	The roll movement controls the ailerons	16.05.2012	A.G
R609.1	A	Passed	The output is according to the requirement	16.05.2012	A.G
R610.2	C	N/T	We do not have access to the actual joystick, it is not yet produced. Equator Aircraft Norway must make sure the joystick is according to requirement	16.05.2012	A.G
R611.3	B	N/T	Our system is prepared for a triple redundant joystick. Equator Aircraft Norway must make sure the joystick is according to the requirement	16.05.2012	A.G

4.7. Control surface

Req. Code	Priority	Result	Description of the result	Date	Test engineer
R702.1	A	N/T	The rotating angle on the stepper motor depends on the SW parameters. Equator Aircraft Norway must make sure the control surfaces can move according to the standards	16.05.2012	A.G
R703.1	A	N/T	The rotating angle on the stepper motor depends on the SW parameters. Equator Aircraft Norway must make sure the control surfaces can move according to the standards	16.05.2012	A.G
R704.1	A	N/T	The rotating angle on the stepper motor depends on the SW parameters. Equator Aircraft Norway must make sure the control surfaces can move according to the standards	16.05.2012	A.G
R706.2	C	N/T	This test cannot be tested with our test bench.	21.05.2012	O.R
R707.2	B	N/T	This test cannot be done without proper loading and gear ratio. But on our test-bench with 1:1 gear ratio we are way within that requirement	21.05.2012	O.R
R708.1	A	Passed/ N/T	The resolution of the stepper motor is 200steps/360˚, with the gearing (10x). 2000 steps /360˚ = 5.5 steps / degree.	16.05.2012	A.G
R709.2	C	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G
R710.2	B	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G
R711.1	A	Passed/ N/T	The resolution of the stepper motor is 200steps/360˚, with the gearing (10x). 2000 steps /360˚ = 5.5 steps / degree.	16.05.2012	A.G
R712.2	C	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G
R713.2	B	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G
R714.1	A	Passed/ N/T	The resolution of the stepper motor is 200steps/360˚, with the gearing (10x). 2000 steps /360˚ = 5.5 steps / degree.	16.05.2012	A.G
R716.2	C	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G

R717.1	A	Passed/ N/T	The Nose gear movement is dependent on the gearing. However the movement of the stepper motor is totally dependent on the SW. The actual resolution of the stepper motor must be calculated when the gearing of the motor is known.	16.05.2012	A.G
R718.2	A	N/T	This has to be tested by Equator Aircraft Norway, when the system is mounted on the aircraft.	23.05.2012	A.G
R719.2	C	N/T	Equator Aircraft Norway have to make sure the resolution is according to the requirement when the nose wheel is mounted.	16.05.2012	A.G

5. REVISIONS

Responsible person for this document, procedure or template

Rev	Description	Date	Name
0.1	Made Templates.	12.01.2012	A.G & O.R
0.2	Made 2.2.1	25.01.2012	A.G
0.3	Made Schematic test results, layout test with results	20.03.2012	O.R
0.4	See: Additional Tests	24.04.2012	A.G
0.5	See: Additional Tests	27.04.2012	A.G
0.6	See: Additional Tests	04.05.2012	O.R
0.7	Made: R102, R105, R106, R107 in 4.1 Made: R216.4, R220.2, R221.2, R222.2, R223.2, R225.2, R226.2, R227.2, R228.2, R229.2, R230.2, R231.2, R232.2 in 4.2 Made: R304.1, R305.2, R306.1, R309.1, R310.1 in 4.3 Made: R501.3, R502.2, R504.2, R505.3, R506.3, R509.1, R510.1, R511.1, R512.1, R518.2, R519.1 in 4.5 Made: 4, 2.	15.05.2012	A.G
0.8	Made: R207.2 in4.2 Made: R601.1, R612.1, R602.2, R603.2, R604.1, R605.1, R606.2, R607.2, R608.1, R609.1, R610.2, R611.3 in 4.6 Made: R702.1, R703.1, R704.1, R708.1, R711.1, R714.1, R717.1, R719.2 in4.7	16.05.2012	A.G
0.9	Made: R224.2	19.05.2012	A.G
0.1	Made: R401.2, R402.2, R404.4, R405.3, R407.3, R408.1, R409.1, R410.1, R411.1, R412.2, R413.1, R414.2, R415.2, R416.1	22.05.2012	K.M
0.11	Made: 205.4, 401.2, R412.2, R709.2, R710.2, R712.2, R713.2, R716.2, R718.2	23.05.2012	A.G
1.0	Made: R513.1, R218.2, R219.2 Made official copy, divided the document	28.05.2012	A.G

Additional Tests

Bachelor Project

Compact Fly-By-Wire System

Version	1.0
Category	Released
Issue Date	29.05.2012
Made by	A.G/O.R
Checked by	A.G
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1. TEST EQUIPMENT LIST

1.1. Sensor Panel

Here you will find the Sensors we will use to simulate different functions and states on the MCC and the SC card.

1.1.1. Motor position sensor

We need a sensor to simulate the position sensors of the control planes, in order to test the closed loop in software. We also need optical sensors that tell us every time the motors are in zero position.

1.1.1.1. Photo Interrupter GP1A57HRJ00F

This is the Digital sensor we will use to simulate the zero position of the motor.
It is an infrared emitter and an infrared detector, when the infrared signal is interrupted the sensor sends out a digital signal.
Ref: http://www.sparkfun.com/products/9299 last checked: 24.04.2012 by A.G

1.1.1.2. 5K OHM Linear Taper Rotary Potentiometer 5KB B5K Pot

This potentiometer works well for measuring the position of a stepper motor. It has a 300 degree ± 10˚ rotary angle, and 10k ohm.
Ref: http://www.ebay.com/itm/5K-OHM-Linear-Taper-Rotary-Potentiometer-5KB-B5K-Pot-/260780963335?pt=LH_DefaultDomain_0&hash=item3cb7c1b607#ht_1507wt_1037 last checked: 24.04.2012 by A.G

1.1.2. Airspeed sensor simulator

The airspeed sensor in the aircraft will measure the increase in air pressure caused by the moving aircraft. This sensor will send out an analog signal.
To simulate the airspeed of the aircraft we will use the same potentiometer as in 1.1.1.2.

1.1.3. Angle of attack sensor simulator

The angle of attack sensor simply measures the difference in angle of the aircraft compared to the direction of the aircraft through the air. It is an analog sensor measuring an angle.
To illustrate this sensor we will use the same potentiometer as in 1.1.1.2

1.1.4. Distance sensor simulator

We use the same sensor that is going to be mounted in the aircraft as the test sensor.

1.1.5. Autopilot set point buttons simulator

We will use some momentary switches to simulate the autopilot set point buttons on the joystick since it is not yet ready for production.
The buttons will be used for:
- (+) altitude
- (-) altitude

- (+) compass heading
- (-) compass heading
- (+) climb rate
- (-) climb rate

All the button functions are set points only. And it is therefore the values the system will work to reach.

1.1.6. Nose wheel Down/up sensor simulator

There will be a sensor that detects when the Nose Wheel is activated. The Nose Wheel Controller on the operating MCC will then be activated. We will simulate this function with a toggle switch.

1.2. Sensor table:

Test sensor:	Pcs	Used for:	Date	Name
Photo Interrupter GP1A57HRJ00F	5	1.1.1 Motor position sensor	24.04.2012	A.G
5K OHM Linear Taper Rotary Potentiometer 5KB B5K Pot	7	1.1.1 Motor position sensor, 1.1.2 Airspeed sensor simulator & 1.1.3 Angle of attack sensor simulator.	24.04.2012	A.G
Momentary buttons	6	1.1.5 Autopilot set point buttons simulator	24.04.2012	A.G
Toggle Switch	1	1.1.6 Nose wheel Down/up sensor simulator	25.04.2012	A.G

1.3. Template

1.3.1. Test Plan

Test #	**Name #**	**Priority:**	**Budgeted hours:**
Description:			
Why:			
How:			
Owner:	**Date:**		

1.3.2. Test Result

Test Result #.x	**Name #**	**Success rate:**	**Accumulated hours:**
Result description:			
Necessary changes:			
Owner:	**Date:**		

1.4. Cables

1.4.1. Test Plan

Test 2.2.1	**Signal interference**	**Priority:**	**Budgeted hours:** 7h
Description:	The analog cable from the joystick to the MCC may be vulnerable to magnetic interference from the generator and from surrounding noise sources.		
Why:	We need to make sure that the analog signals are disturbed as little as possible from the joystick to the MCC		
How:	We will send some analogue signals trough a normal signal cable in the EMC-room at HiBu. We will then measure the signal loss. We will repeat the test for a shielded cable and compare the results. We also have to test the signal interference the power (5V) is inducing on the signals from the potentiometers. And then decide if we need to separate the signal cables and the power cables to the joystick due to the interference.		
Owner: A.G	**Date:** 25.01.2012		

2. HARDWARE

These test are not part of the requirements but are needed.

2.1. MCC

2.1.1. **Schematic test**		**Priority:**	**Budgeted hours: 8**
Description:	This test is the first to ensure that the circuit board is correct. We are going to use isis to simulate the schematic and run a basic code on the microcontroller.		
Why:	We need to confirm that our circuit is connected the way it is supposed to be. This can save us a lot of time if we get the circuit right on the first try!		
How:	We need to make a dummy code for our microcontroller that sets one pin high and then scans through all the pins on our controller. In that way we can assure us that all of our connections is wired properly by “measure” voltage in our simulator. This has to me done for both SC and MCC schematics.		
Owner: O.R	**Date: 7.03.2012**		

2.1.1.1. **Schematic test**	**Success rate:**	**Accumulated hours: 5**
Result description:	We made a simple code which toggles one pin on the microcontroller this went well and everything was connected properly ☺I	
Necessary changes:	N/A	
Owner:	**Date: 12.03.2012**	

2.1.2. **Layout test**	**Priority:**	**Budgeted hours: 4**
Description:	When we make the PCB-layout we need to cross check that we make the right connections as we go, it is very important that the person who makes the layout in Ares has control over the system and can recognize if the signal and power lines when it is routed.	
Why:	We need to do this test so we don't make a pcb-card that doesn't function properly.	
How:	When the card is routed, we need to check the card configuration document so we know that the routes are correct.	
Owner: O.R	**Date: 19.03.2012**	

2.1.2.1. **Layout test**	**Success rate:**	**Accumulated hours: 0.5**
Result description:	The layout and schematic was cross checked with card configuration and we needed to update the card configuration. We need to cross check that all the microcontroller pins are compatible with the signal that it is connected to.	
Necessary changes:	We needed to change the card configuration so it is compatible.	
Owner: O.R	**Date: 19.03.2012**	

2.1.3. Parallel stepper controllers

Priority:9 | **Budgeted hours: 3**

Description: We are testing to see how the stepper controllers is reacting if they are paralleled

Why: We need to determine if our redundant system is causing more trouble to the stepper controllers than it helps.

How:

Controller test	Result	Date
Test		
Controller 1 disabled and controller 2 is running		
Controller 1 unpowered and controller 2 is running		
Controller 1 enabled but not stepped and controller 2 is running		
Both controllers is activated and stepping		
Controllers are alternating the enable pins		

This is the form we're going to use to see if the controllers can operate simultaneously. We're connecting

Owner: O.R | **Date: 04.05.2012**

2.1.3.1. Stepper controller redundancy test

Success rate: 9 | **Accumulated hours: 3**

Result description:

Controller test	Result	Date
Test	Works	04.05.2012
Controller 1 disabled and controller 2 is running	Works	04.05.2013
Controller 1 unpowered and controller 2 is running	Works	04.05.2014
Controller 1 enabled but not stepped and controller 2 is running	Works	04.05.2015
Both controllers is activated and stepping	One enters protection mode, one needs to be reset	04.05.2016
Controllers are alternating the enable pin.	Works	04.05.2017

Necessary changes: None, but we learned that we might need to use the reset pin if something fails. And we need to make our software aware of this problem.

Owner: O.R | **Date: 04.05.2012**

3. REVISIONS

Rev	Description	Date	Name
0.1	Made Templates.	12.01.2012	A.G & O.R
0.2	Made 2.2.1	25.01.2012	A.G
0.3	Made Schematic test results, layout test with results	20.03.2012	O.R
0.4	Made:1.1, 1.1.1, 1.1.1.1, 1.1.1.2, 1.1.2, 1.1.3, 1.1.4, 1.1.5	24.04.2012	A.G
0.5	Made: 1.1.6	27.04.2012	A.G
0.6	Made test: See Test Results	04.05.2012	O.R
0.7	Rearranged and divided the document	28.05.2012	A.G

Improvement Recommendations

Group 3

Compact Fly-by-wire system

Version	1.0
Category	Released
Issue Date	28.05.2012
Made by	S.A
Checked by	K.M
Approved by	K.M

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1. ABBREVIATION

Technical Term	Standard Definition
K.M.	Kjetil Mjøs
A.G.	Axel Gravningsbråten
S.A.	Sindre Andersen
T.A.	Thomas Andersen
R.L.	Runar Løken
O.R.	Ole Riiser

Table 1: Abbreviation

2. PURPOSE

Our assignment was to make a proof of concept that demonstrates that a FBW system can make flying safer and simpler. Therefore we made a fully functional proof of concept, however in order to making a prototype it needs improvements described below.

(DISCLAIMER: The improvements below are what we see as necessary changes, there are surely more improvements that can be done.)

3. IMPROVEMENTS

3.1. Hardware

3.1.1. General

- It should be used connectors and connection points designed for tough environments. Specially to keep dust, water and other external influences from making corrosion and/or bad connection.
- The system should be mounted in a closed metal box or baked in a form together with for example epoxy to prevent the cards to be exposed from the outer world, such as an ECU for cars.
- The card should be created using 4-layers to improve the inductance, ground plane issues and to have different layers dedicated to one thing. For example top layer as power plane, the two layers between as routing layers and the bottom layer as ground plane. This setup will create a Faraday cage and will exclude magnetic interference.
- It should be used surface-mounted components instead of through-hole to decrease the mass of the component and the inductance in the component legs, this will also make them more resistant to vibrations.
- It should also be done a job regarding ground plane problems. If the card will be created as 4-layers it will remove some of these issues.
- The cards should be mounted inside a metal box and ground should be connected to the box to create a good ground connection. This electric field will lead to better shielding. The screw holes internally on the cards should be connected with the ground plane to have more ground connections.

3.1.2. MCC

- It should be made some more spare connectors on the cards to have all the pins on the microprocessor available.

3.1.3. SC

- It should be chosen an IMC designed for tough environments. Since our product is a proof of concept and we have a small budget compared to the final system, we did not feel it necessary to choose an expensive module special designed for this application.

3.1.4. HMI

- It should be used buttons which are connected to each other mechanically to prevent two MCC cards to be activated at the same time. This means that if you activate one button, all of the other will be deactivated.

3.1.5. Joystick

- It should be used a redundant joystick using non-contact sensors to minimize the wear of the mechanics of the joystick and potentiometers.

3.2. Software

3.2.1. General

To ensure that every code on the three MCC's is different it should be written by different persons. This is to not have one software error that can happen on all the MCC's at the same time.

3.2.2. Watchdog timer

A watchdog timer is a microcontroller function that resets the code if it has been hanging in the same loop for a specific amount of time. To get this function to work properly you would need to calculate how much time every function use and reset the watchdog timer on appropriate places.

3.2.3. Sensor reading

Sensors on SC need to be read. The best way of doing this would be to make a class for every sensor and find a suitable update time for them.

3.2.4. Autopilot

When all sensors are correctly read into the system an autopilot can be implemented. The data can then be sent to the MCC's to control the stepper motors and get the airplane to follow the coordinates.

3.2.5. Android tablet

The digital HMI interface to the pilot is going to be an Android tablet. The tablet is connected to SC via a USB cable. An USB library needs to be made for the supervisor in order to be able to send data to the tablet. An android app with an intuitive GUI also needs to be made.

3.2.6. Code optimalization

The MCC's are using an 8bit controller. The code can be optimized for this processor in order to make it more efficient.

3.2.7. Stepper motor acceleration

To get the optimal performance of a stepper motor it needs to have a controlled acceleration. The first steps needs to be slow before it can speed up to ensure the motors does not skip a step.

4. REVISIONS

Responsible person for this document, procedure or template

rev	Description	Date	Name
01	Created this document and made all of the improvements on MCC, general, SC, HMI, Joystick and software improvements	25.05.2012	S.A, K.M
1.0	Checked the document for errors, did small changes and changed the name of the document from Improvement Document to Improvement recommendations.	28.05.2012	A.G

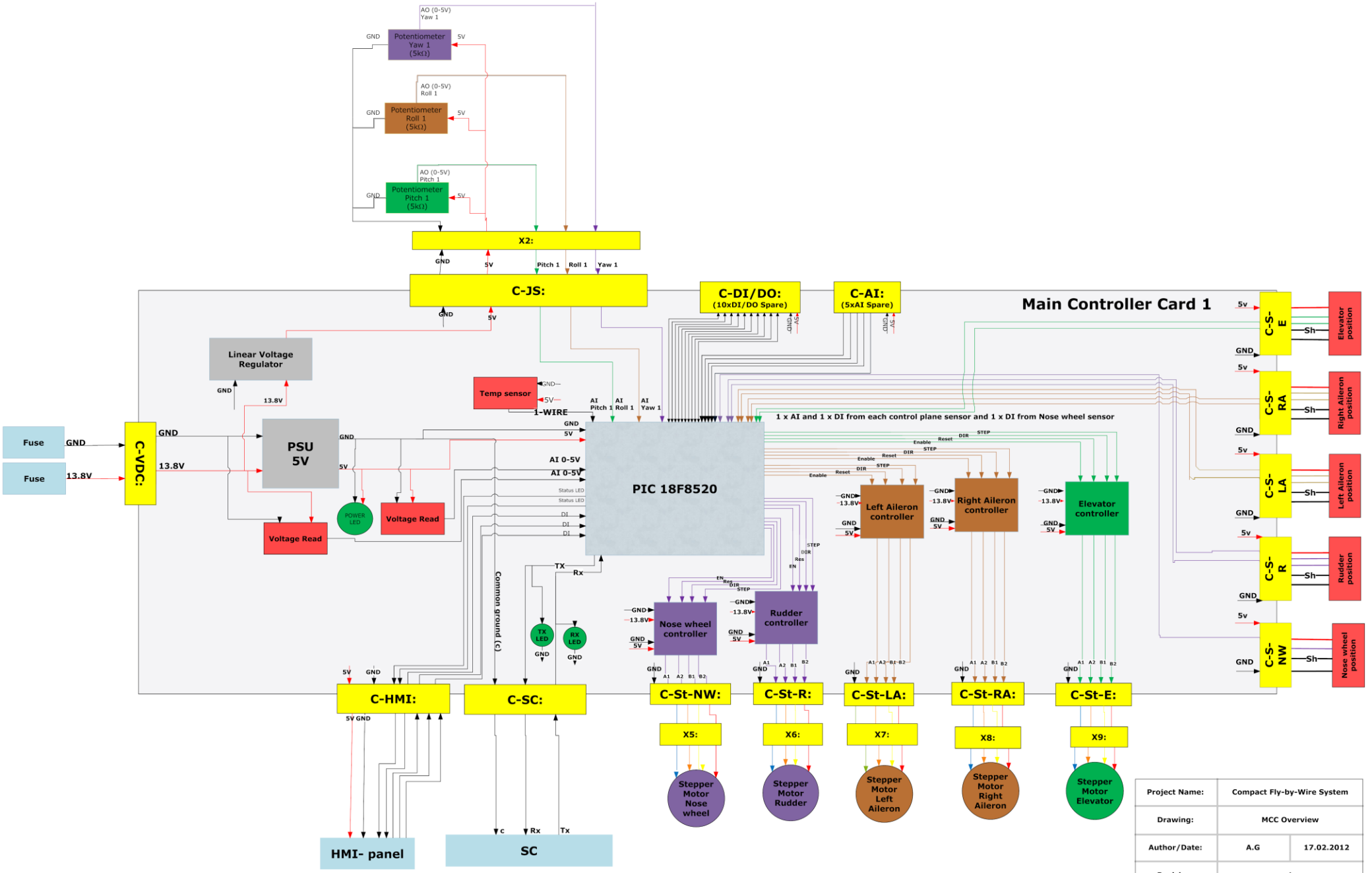
Table 2: Revisions

Conclusion:

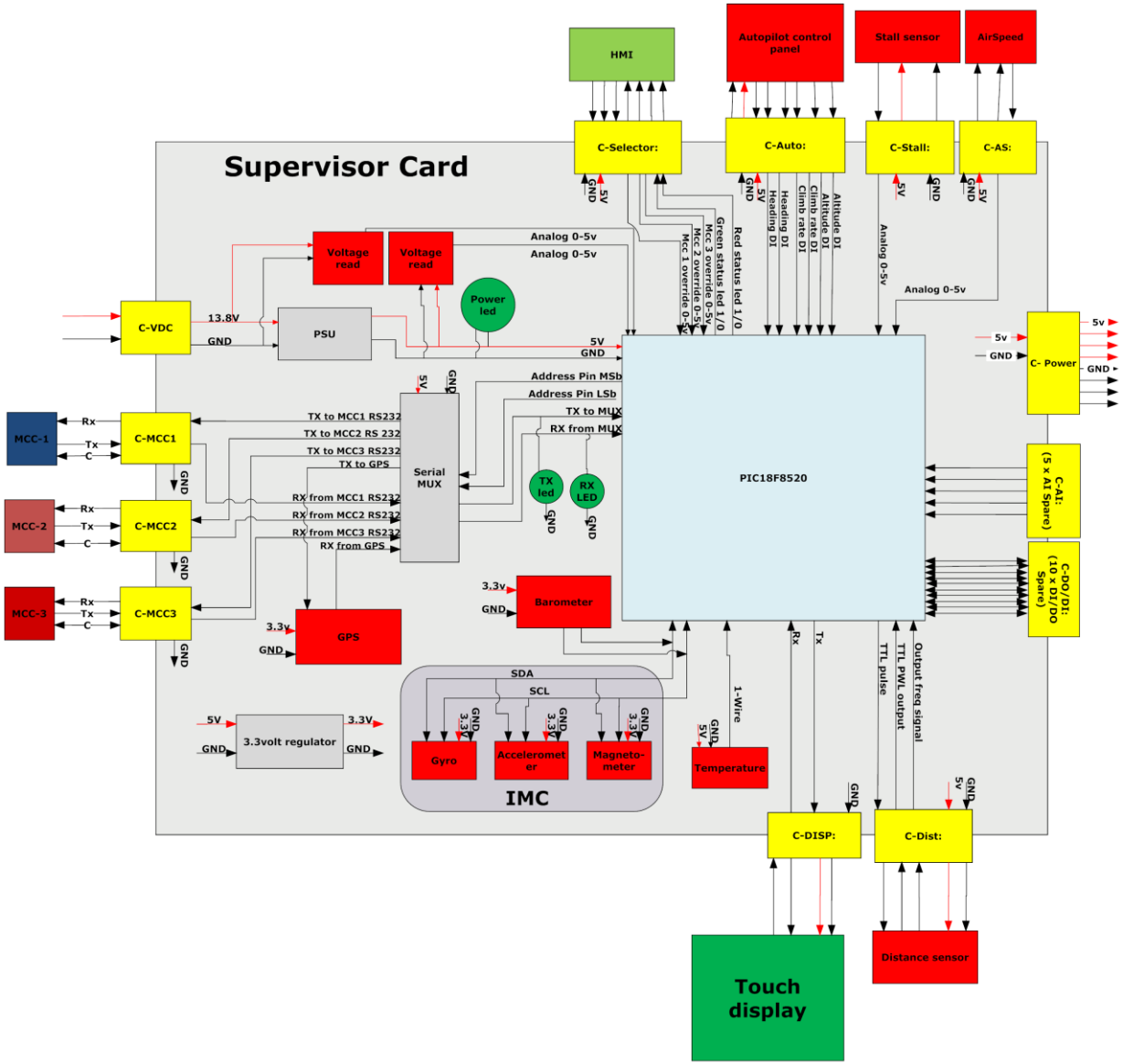
The system we made is an important step within the small plane aviation industry. We have proven that it is possible to make a cheap and available Fly-By-Wire system that can easily be implemented in most small airplanes. The system makes the airplane lighter, safer and gives the pilot a simpler environment with a lot of extra features that can prevent fatal pilot errors.

During our project we have come up with a lot of solutions, some are good and some need more work. The biggest challenges we encountered was not to choose the simplest solution, but one that could be further developed. One example was by changing the controller on the supervisor card from an 8bit to a 32bit controller which we did in April. Another challenge was to make the system redundant, they need to work together but they also need to be fully independent if one controller crashes.

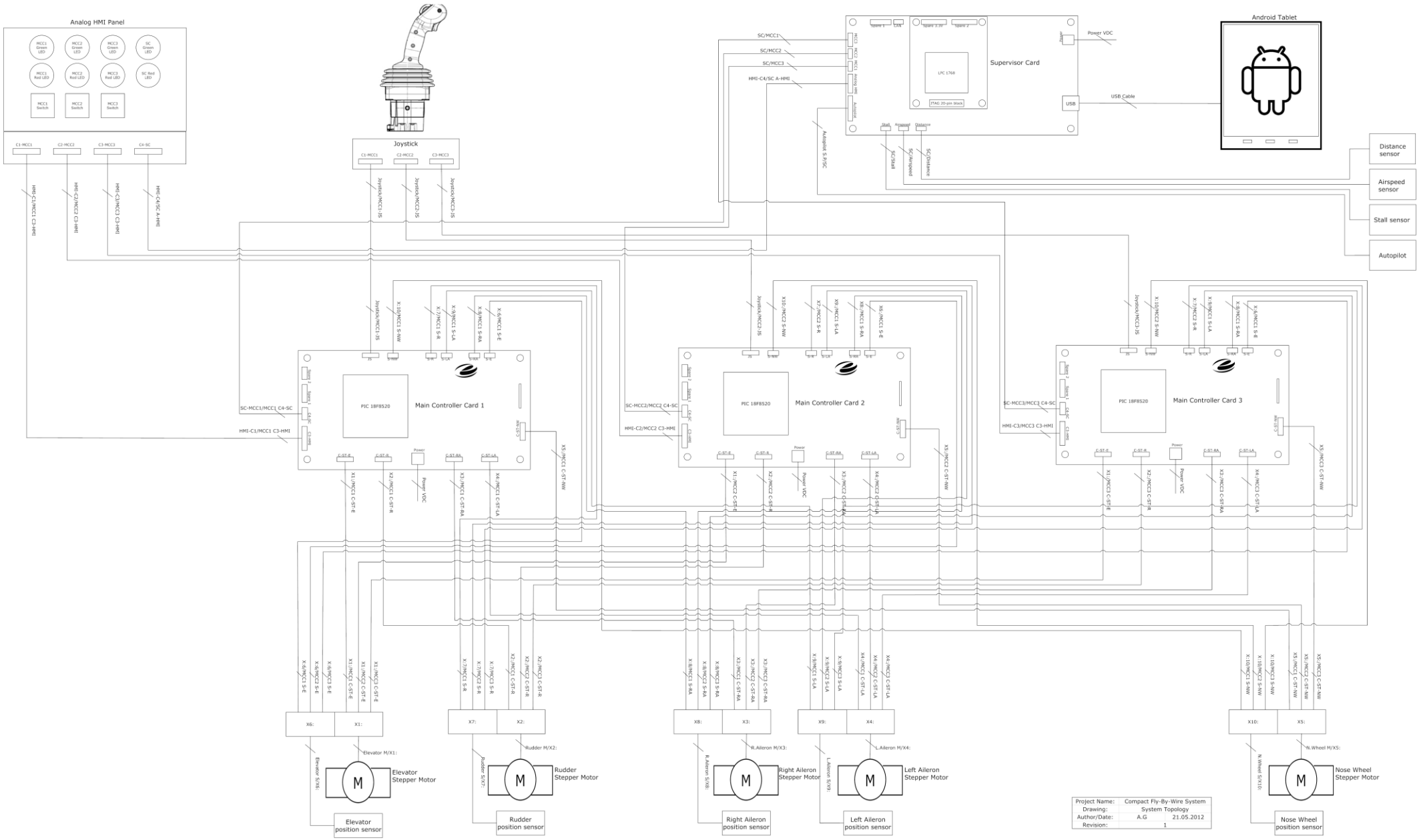
Altogether we are proud of what we have done in six months and we hope our product can be used as a platform for further development of the Compact Fly-By-Wire System. And later we hope it will be used in the Equator P2 Excursion.

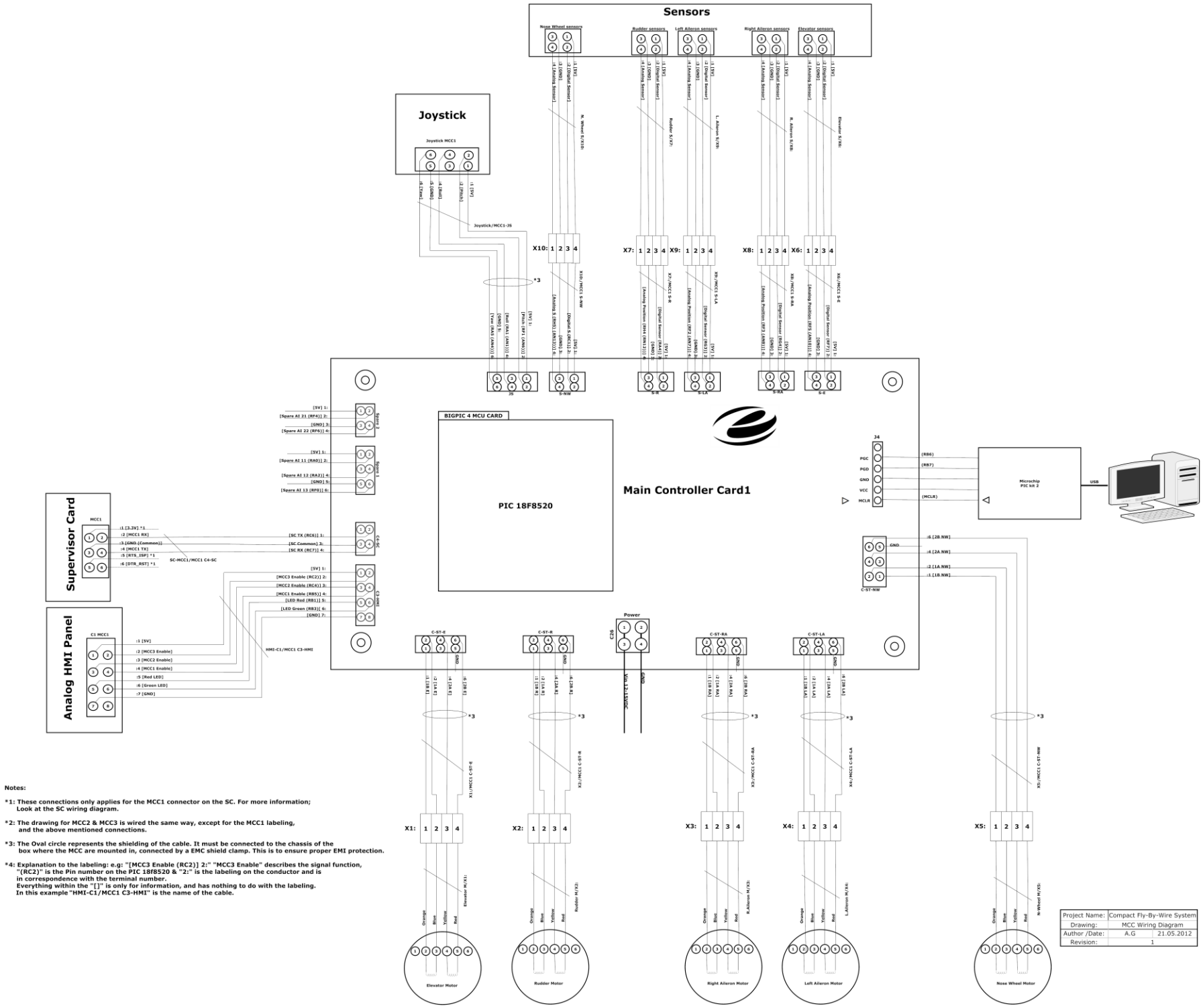


Project Name:	Compact Fly-by-Wire System	
Drawing:	MCC Overview	
Author/Date:	A.G	17.02.2012
Revision:	1	



Project Name:	Compact Fly-by-Wire System	
Drawing:	SC Overview	
Author/Date	O.R	16.02.2012
Revision	1	


Analog HMI Panel
MCC1 Green LED
MCC2 Green LED
MCC3 Green LED
SC Green LED
MCC1 Red LED
MCC2 Red LED
MCC3 Red LED
SC Red LED
MCC1 Switch
MCC2 Switch
MCC3 Switch
C1-MCC1
C2-MCC2
C3-MCC3
C4-SC
Joystick
Supervisor Card
LPC 1768
JTAG 20-pin block
Android Tablet
USB
USB Cable
Power VDC
SC/MCC1
SC/MCC2
SC/MCC3
HMI-C4/SC A-HMI
Autopilot S/P/SC
SC/Stall
SC/Airspeed
SC/Distance
Distance sensor
Airspeed sensor
Stall sensor
Autopilot
Main Controller Card 1
Main Controller Card 2
Main Controller Card 3
PIC 18F8520
Power
Power VDC
SC-MCC1/MCC1 C4-SC
HMI-C1/MCC1 C3-HMI
SC-MCC2/MCC2 C4-SC
HMI-C2/MCC2 C3-HMI
SC-MCC3/MCC3 C4-SC
HMI-C3/MCC3 C3-HMI
Joystick/MCC1-3S
Joystick/MCC2-3S
Joystick/MCC3-3S
X1:/MCC1 C-ST-E
X2:/MCC1 C-ST-R
X3:/MCC1 C-ST-RA
X4:/MCC1 C-ST-LA
X5:/MCC1 C-ST-NW
X1:/MCC2 C-ST-E
X2:/MCC2 C-ST-R
X3:/MCC2 C-ST-RA
X4:/MCC2 C-ST-LA
X5:/MCC2 C-ST-NW
X1:/MCC3 C-ST-E
X2:/MCC3 C-ST-R
X3:/MCC3 C-ST-RA
X4:/MCC3 C-ST-LA
X5:/MCC3 C-ST-NW
X6: X1:
X7: X2:
X8: X3:
X9: X4:
X10: X5:
Elevator M/X1:
Rudder M/X2:
R.Aileron M/X3:
L.Aileron M/X4:
N.Wheel M/X5:
Elevator Stepper Motor
Rudder Stepper Motor
Right Aileron Stepper Motor
Left Aileron Stepper Motor
Nose Wheel Stepper Motor
Elevator position sensor
Rudder position sensor
Right Aileron position sensor
Left Aileron position sensor
Nose Wheel position sensor
Project Name: Compact Fly-By-Wire System
Drawing: System Topology
Author/Date: A.G 21.05.2012
Revision: 1



Notes:

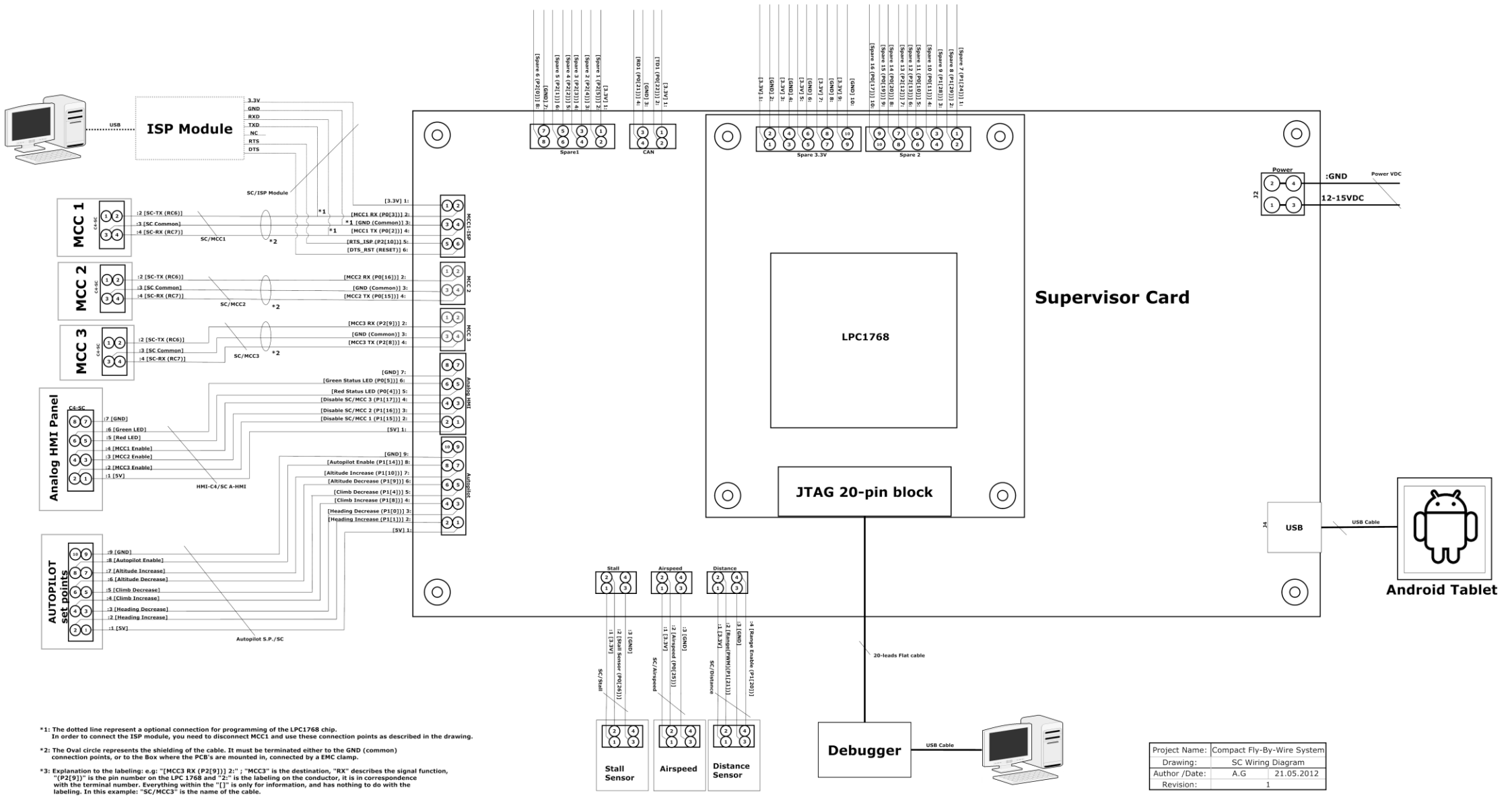
***1: These connections only applies for the MCC1 connector on the SC. For more information; Look at the SC wiring diagram.**

***2: The drawing for MCC2 & MCC3 is wired the same way, except for the MCC1 labeling, and the above mentioned connections.**

***3: The Oval circle represents the shielding of the cable. It must be connected to the chassis of the box where the MCC are mounted in, connected by a EMC shield clamp. This is to ensure proper EMI protection.**

***4: Explanation to the labeling: e.g: "[MCC3 Enable (RC2)] 2:" "MCC3 Enable" describes the signal function, "(RC2)" is the Pin number on the PIC 18f8520 & "2:" is the labeling on the conductor and is in correspondence with the terminal number. Everything within the "[]" is only for information, and has nothing to do with the labeling. In this example "HMI-C1/MCC1 C3-HMI" is the name of the cable.**

Project Name:	Compact Fly-By-Wire System
Drawing:	MCC Wiring Diagram
Author /Date:	A.G 21.05.2012
Revision:	1

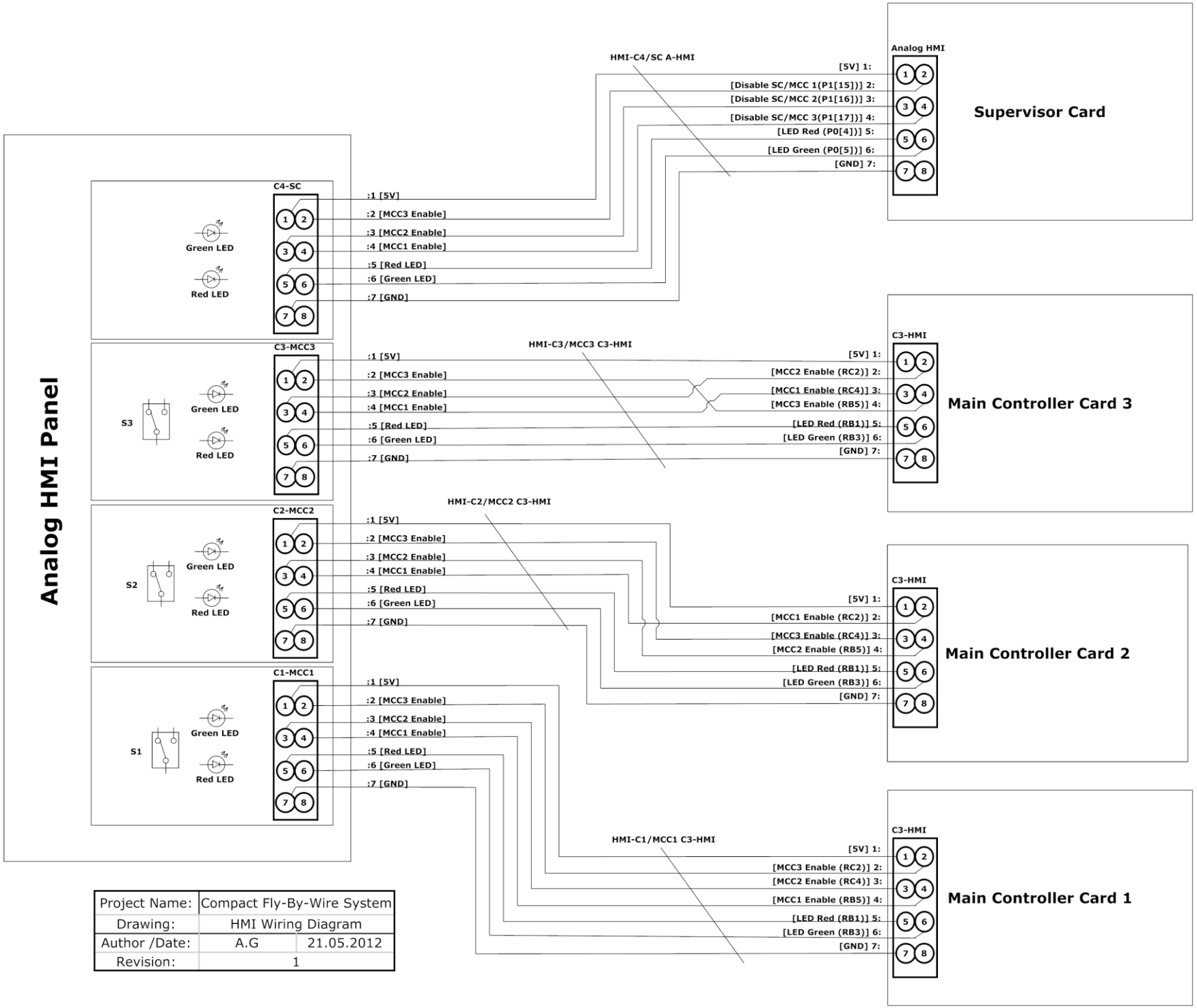


*1: The dotted line represent a optional connection for programming of the LPC1768 chip.
In order to connect the ISP module, you need to disconnect MCC1 and use these connection points as described in the drawing.

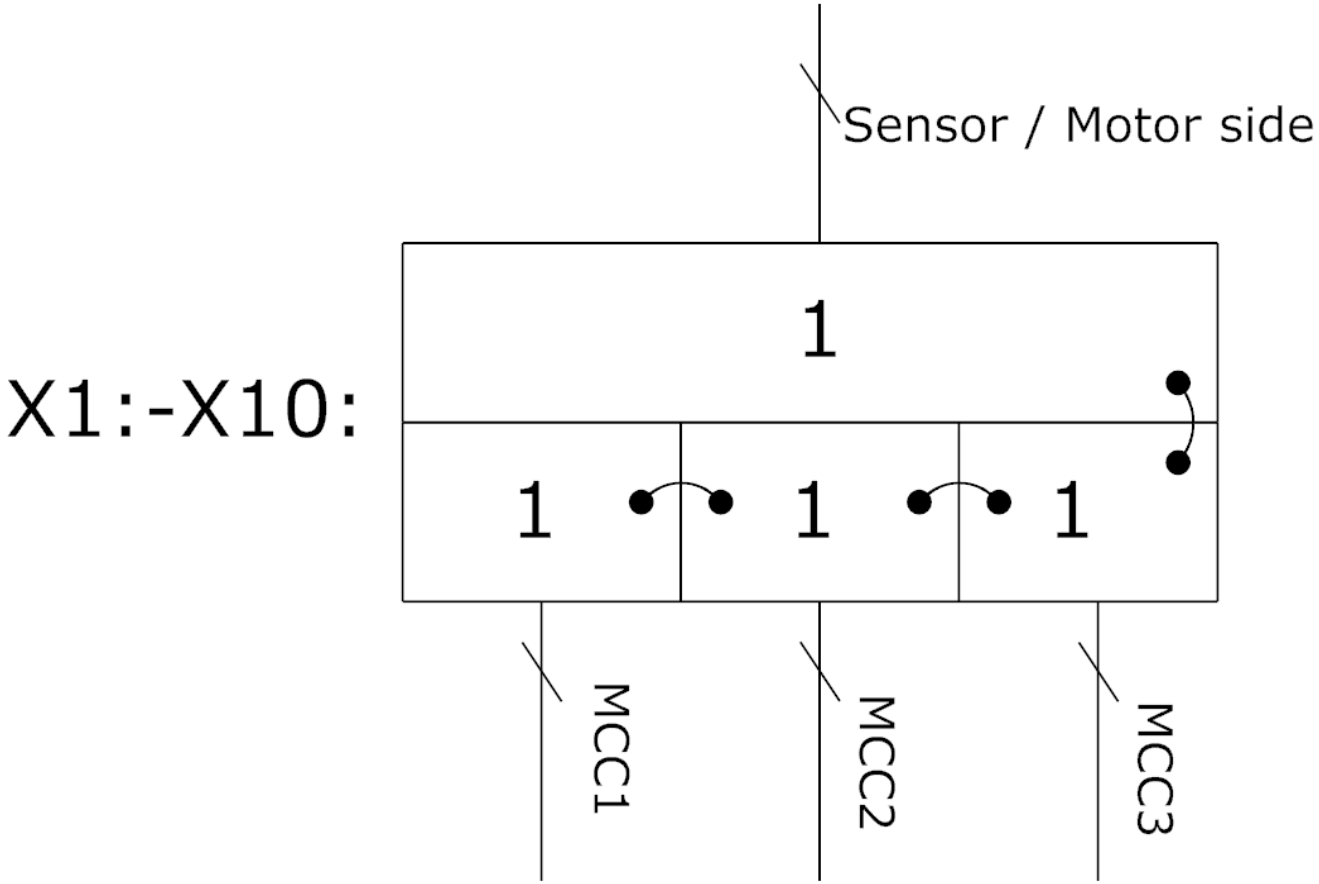
*2: The Oval circle represents the shielding of the cable. It must be terminated either to the GND (common) connection points, or to the Box where the PCB's are mounted in, connected by a EMC clamp.

*3: Explanation to the labeling: e.g: "[MCC3 RX (P2[9])] 2:" ; "MCC3" is the destination, "RX" describes the signal function, "(P2[9])" is the pin number on the LPC 1768 and "2:" is the labeling on the conductor, it is in correspondence with the terminal number. Everything within the "[]" is only for information, and has nothing to do with the labeling. In this example: "SC/MCC3" is the name of the cable.

Project Name:	Compact Fly-By-Wire System	
Drawing:	SC Wiring Diagram	
Author /Date:	A.G	21.05.2012
Revision:	1	

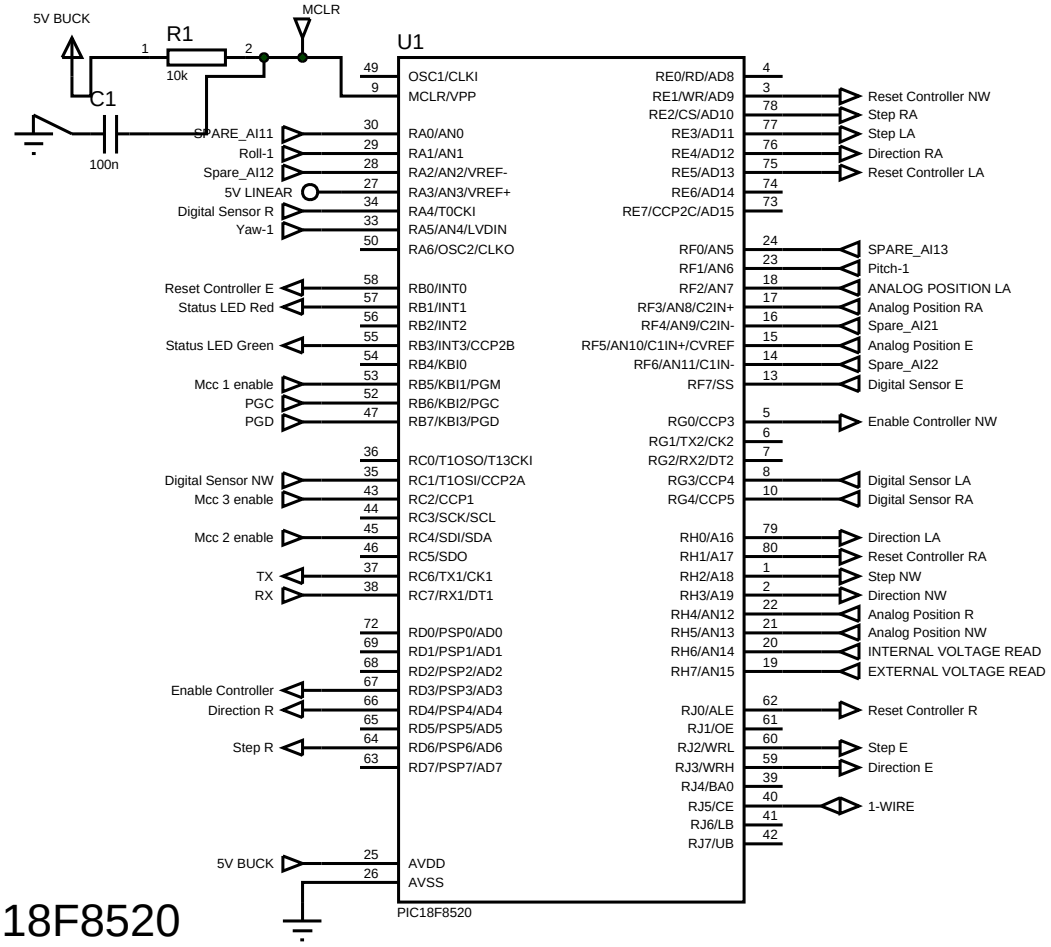


Project Name:	Compact Fly-By-Wire System	
Drawing:	HMI Wiring Diagram	
Author /Date:	A.G	21.05.2012
Revision:	1	



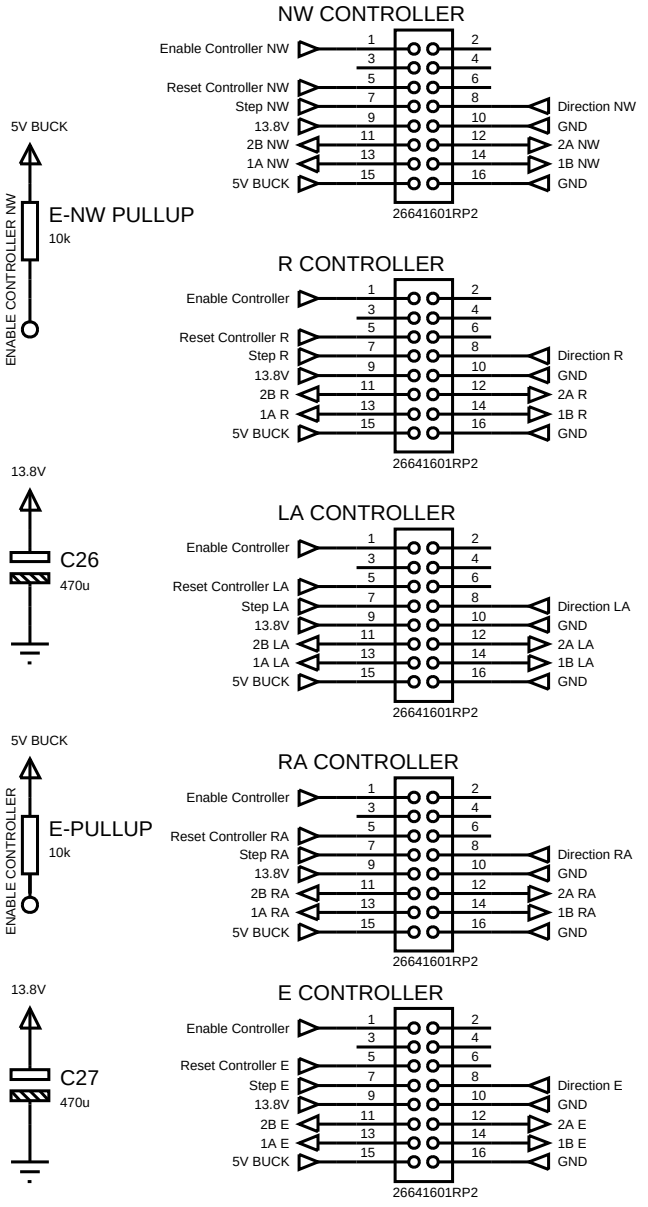
*1: All the terminal blocks (X1: to X10:) in the system topology and in the MCC wiring diagram consists of four connection points connected together with jumpers.

Project Name:	Compact Fly-By-Wire System	
Drawing:	Terminal Block	
Author/Date:	A.G	21.05.2012
Revision	1	

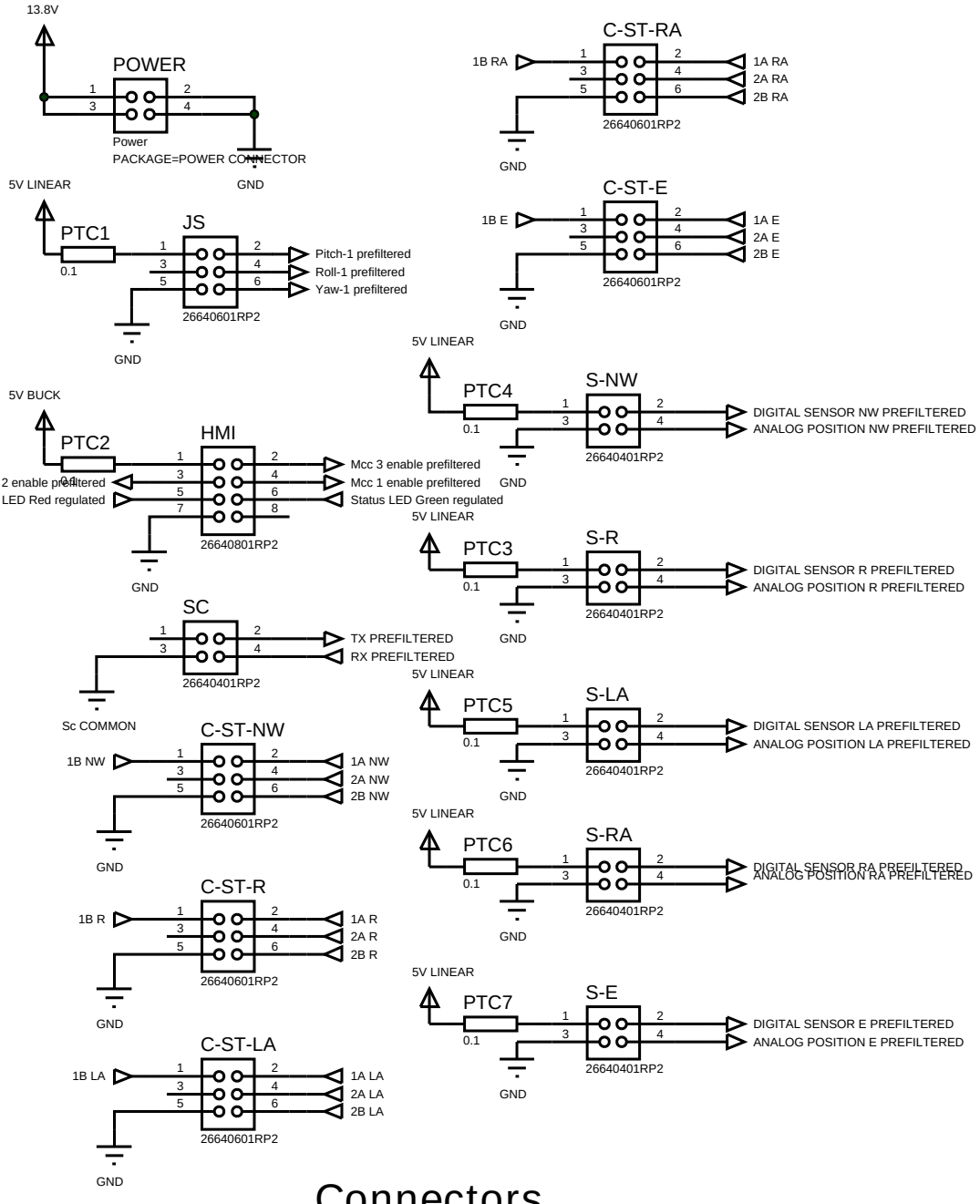


PIC18F8520

Compact-Fly-by-Wire Main Controller Card Component schematic	
Author: Sindre Andersen Date: 21.05.2012	Version: 1

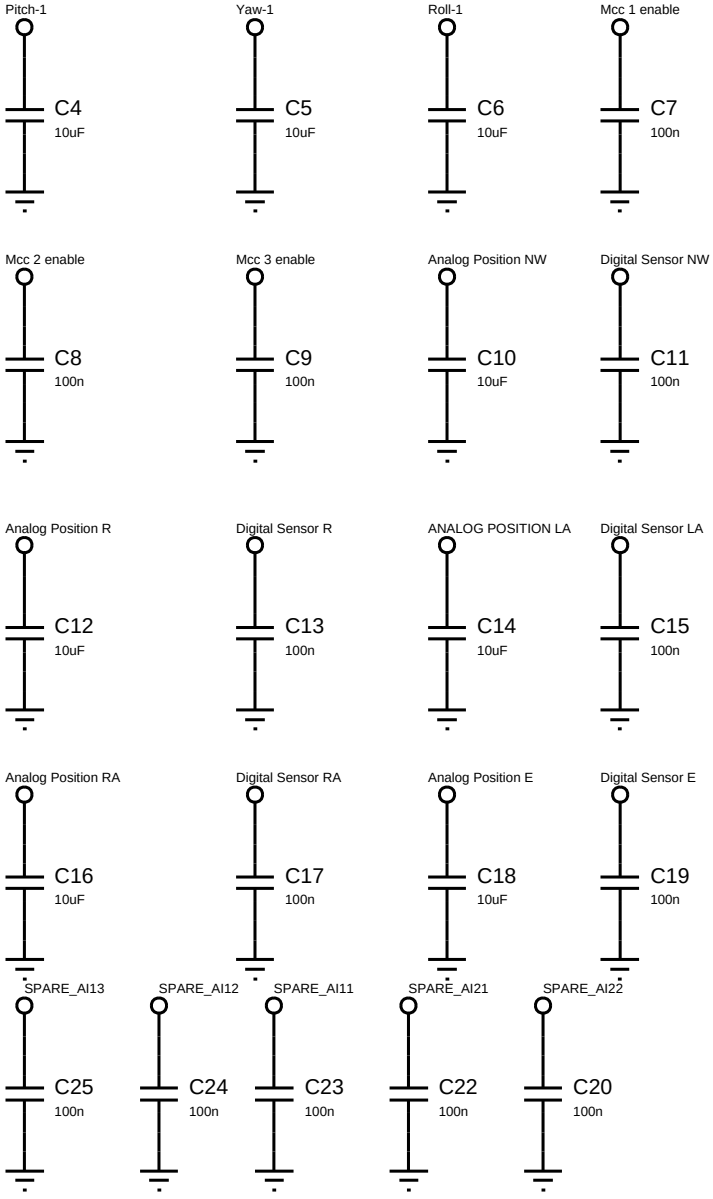


Stepper Controllers

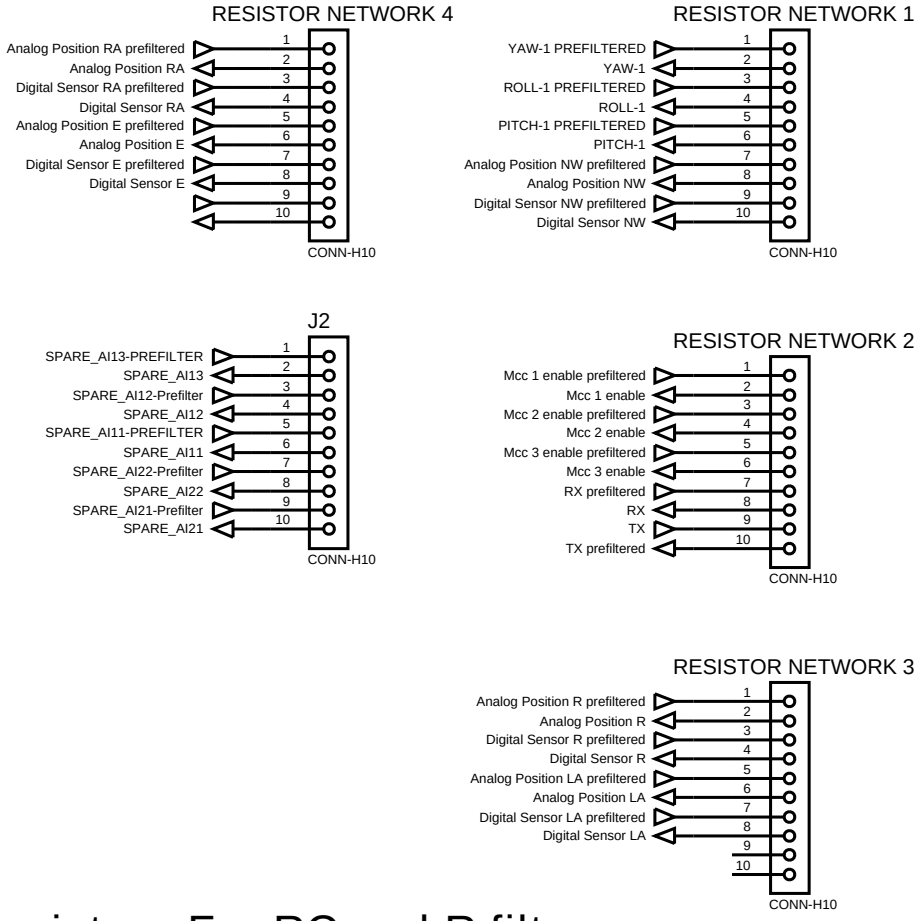


Connectors

Compact-Fly-by-Wire Main Controller Card Component schematic	
Author: Sindre Andersen Date: 21.05.2012	Version: 1



Rc-Filter Caps



Resistors For RC and R filters

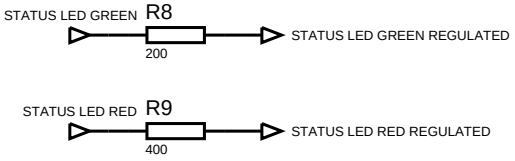
Compact-Fly-by-Wire Main Controller Card

Component schematic

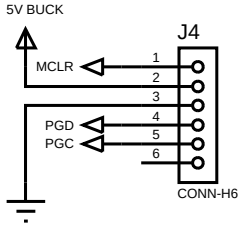
Author: Sindre Andersen

Date: 21.05.2012

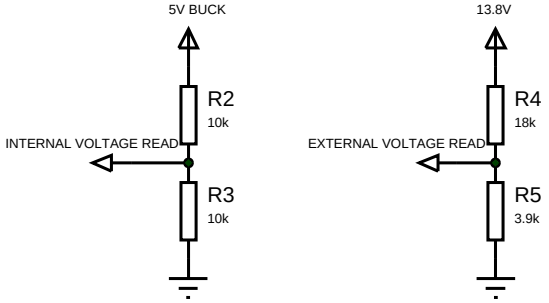
Version: 1



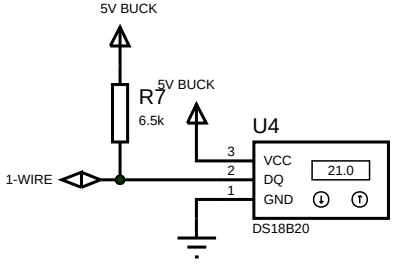
Current Limiters For HMI LEDs



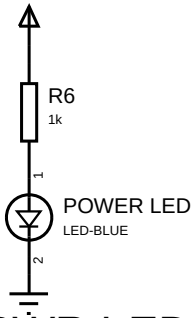
PICKIT Connector



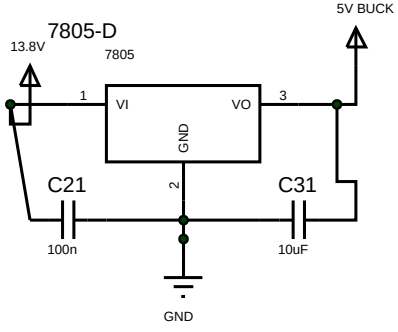
Voltage Read



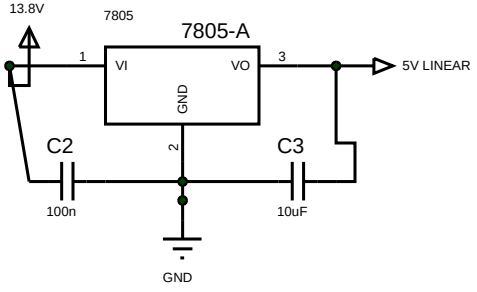
Temp Sens



PWR LED

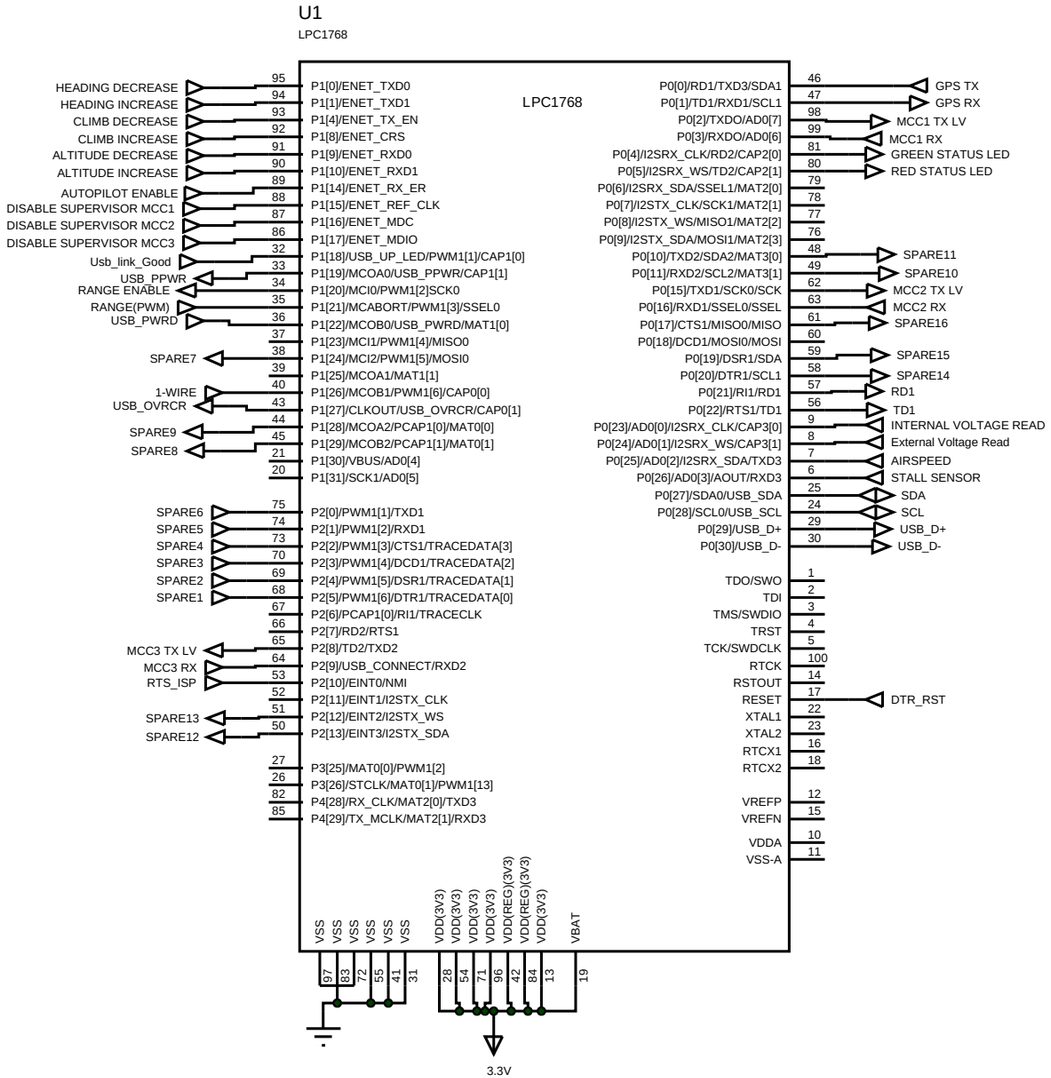


5V Reg



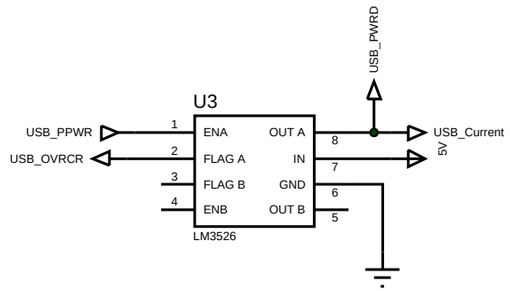
Reg for Analog devices

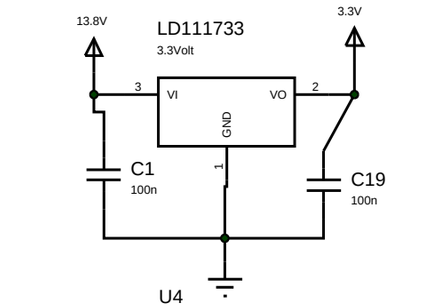
Compact-Fly-by-Wire Main Controller Card Component schematic	
Author: Sindre Andersen Date: 21.05.2012	Version: 1

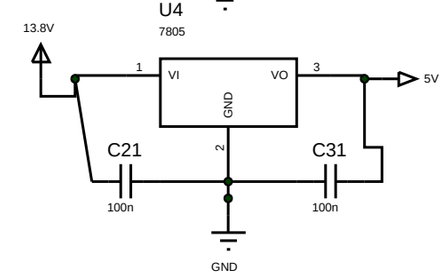


LPC1768

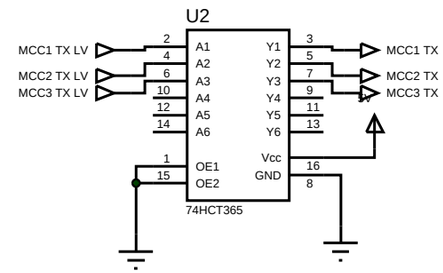
Regulators



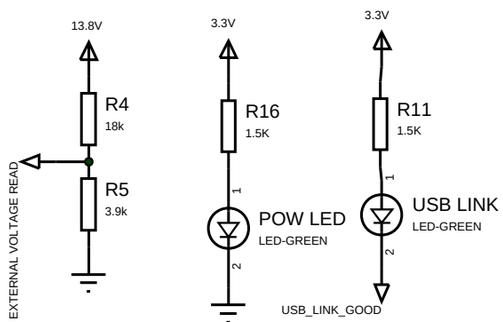


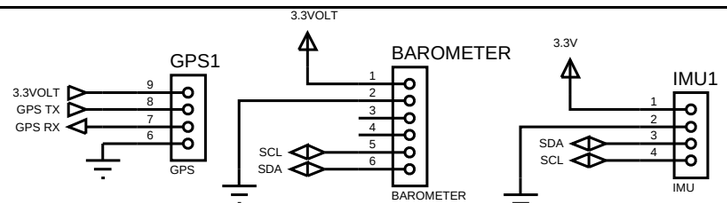


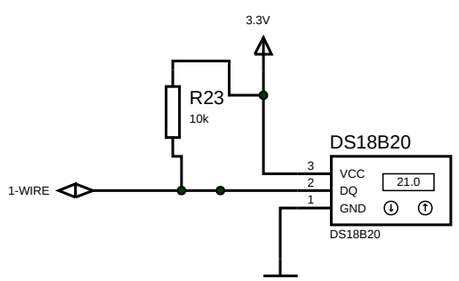
Logic level translation



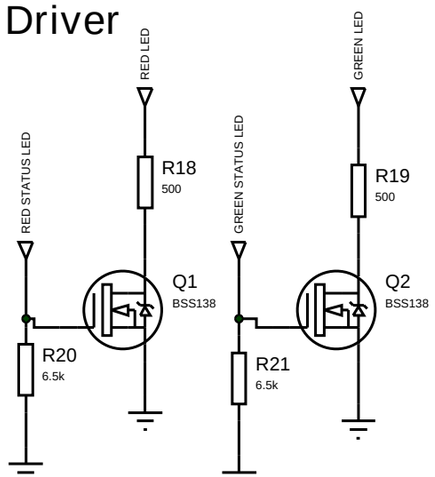
Internal Sensors And status



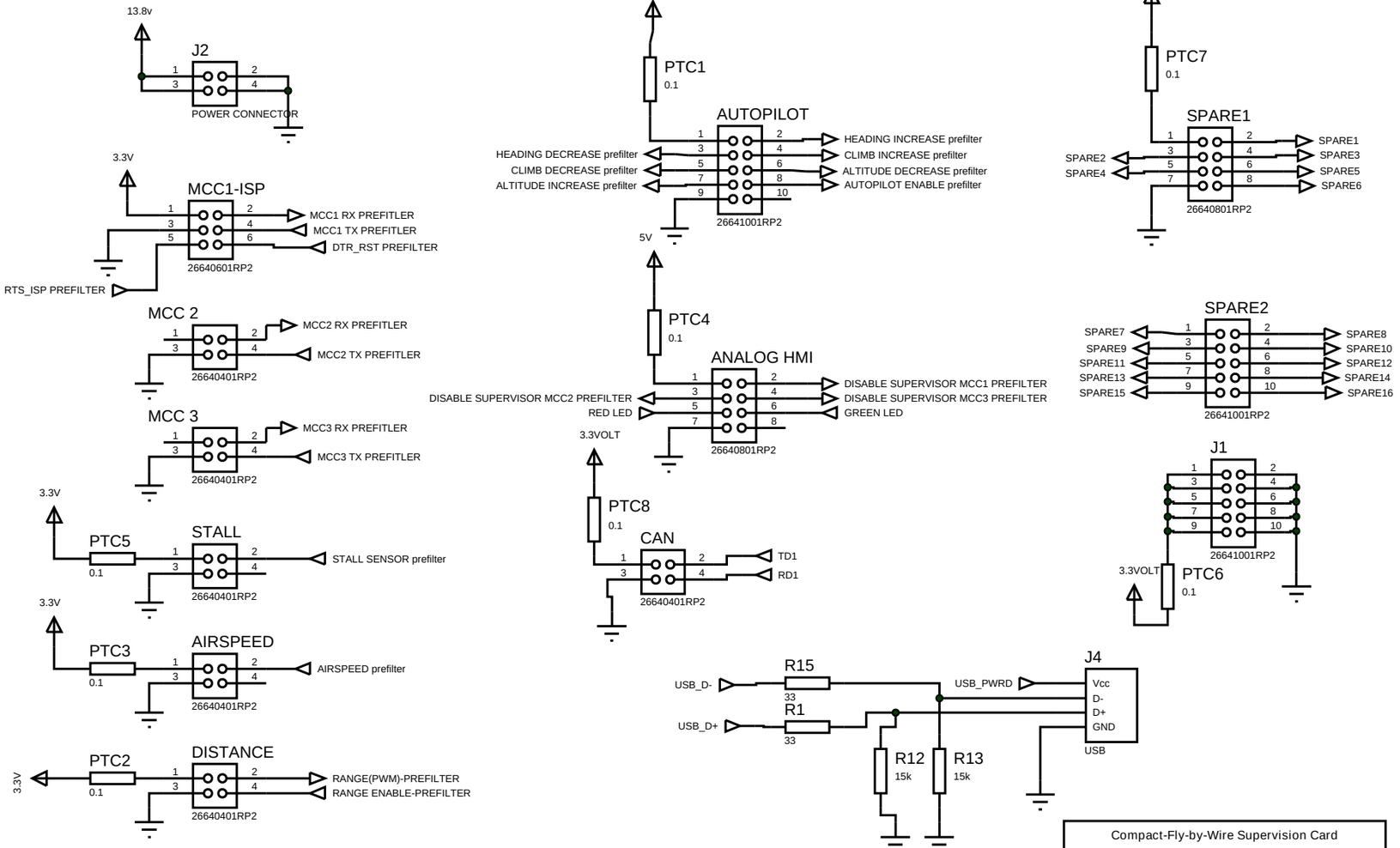




LED Driver

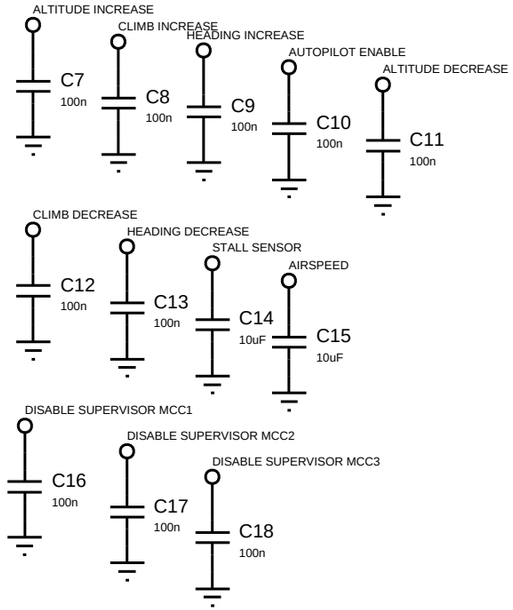


Compact-Fly-by-Wire Supervision Card Sensors and IC	
Author: Ole Riiser Date: 21.05.2012	Version:1

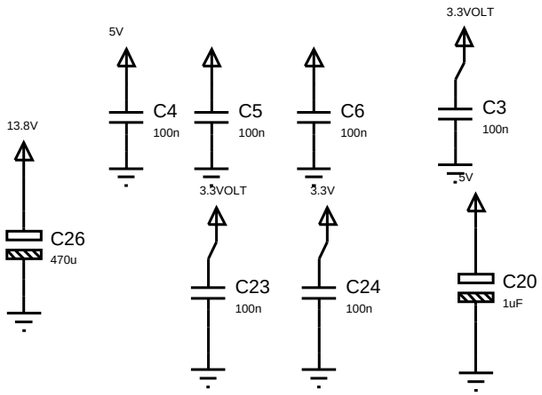


External Connectors

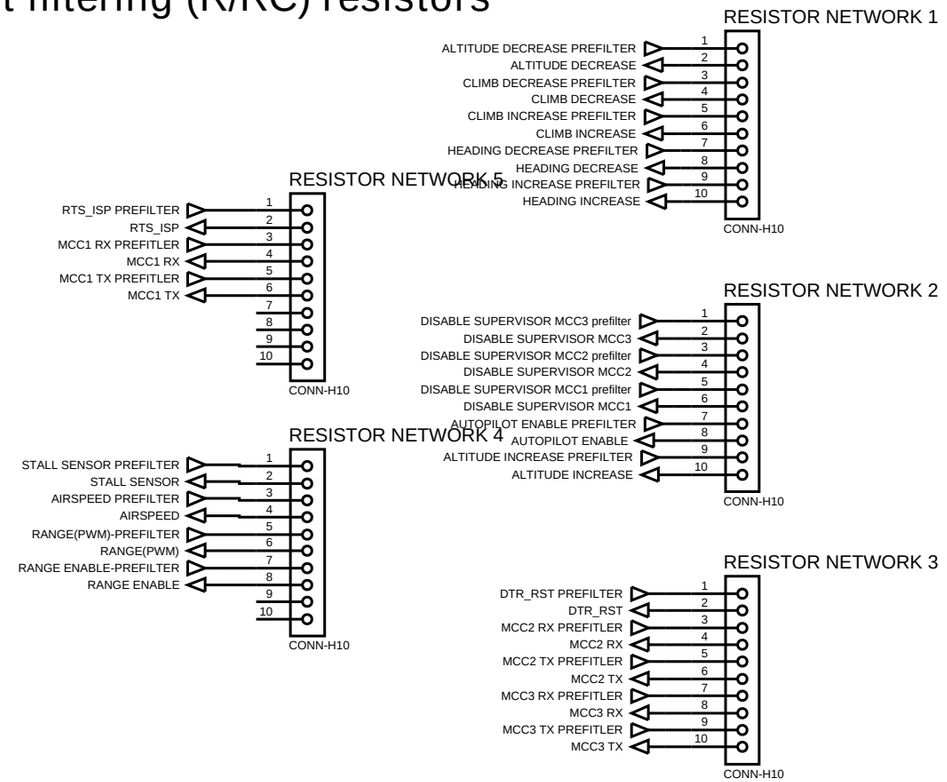
RC filter Caps



Decoupling Caps



Input filtering (R/RC) resistors



Compact-Fly-by-Wire Supervision Card RC filtering and decoupling caps	
Author: Ole Riiser Date: 21.05.2012	Version:1

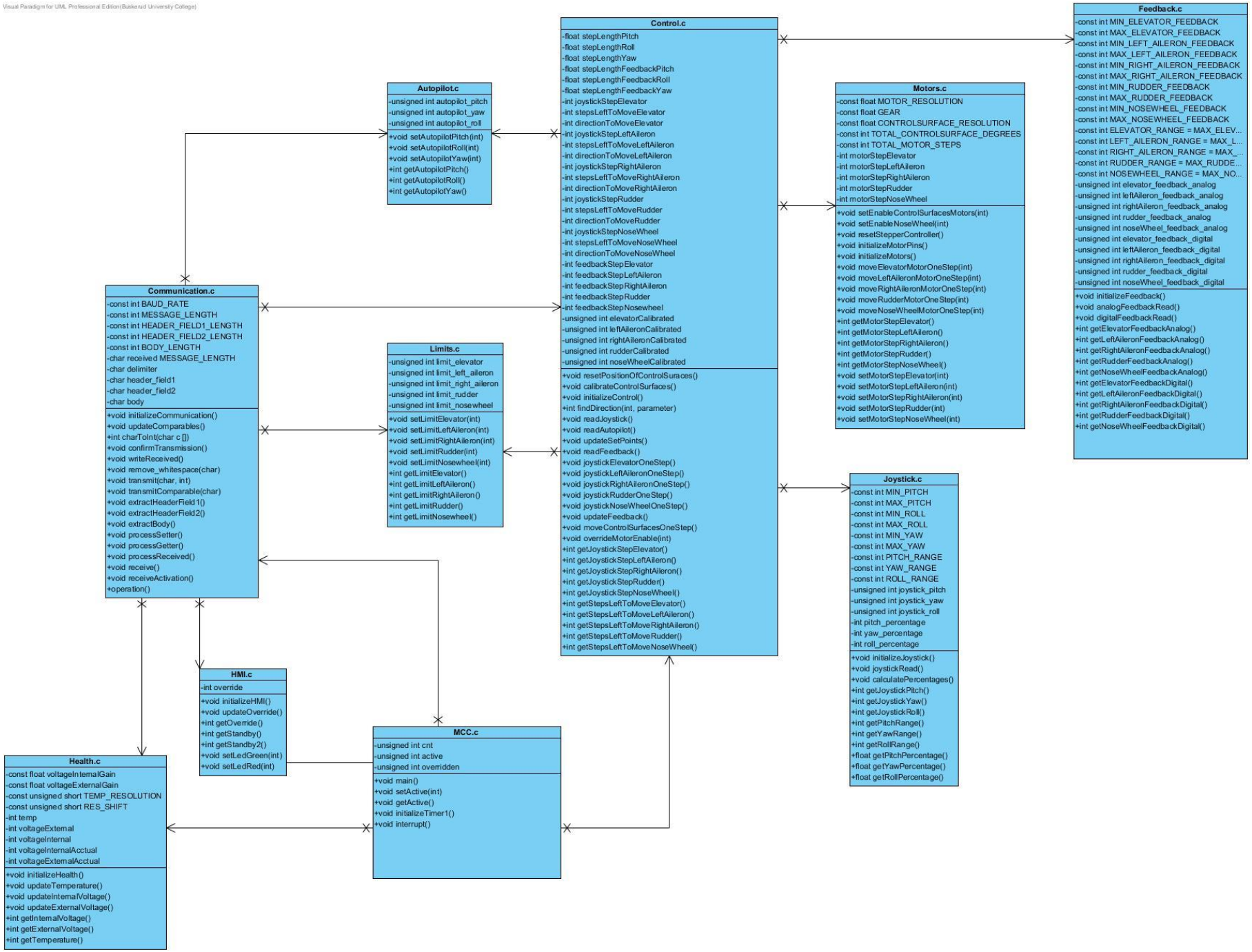
Bill Of Materials
==========
Design: D:\Dropbox\equator_hibu_2012\Proteus\MCC_Rev0.2.DSN
Doc. no.: <NONE>
Revision: <NONE>
Author: Ole A. Riiser
Created: 22/02/12
Modified: 05/11/12

QTY	PART-REFS	VALUE	CODE
Resistors			
5	R1-R3, E-NW PULLUP E-PULLUP	10k	
1	R4	18k	
1	R5	3.9k	
1	R6	1k	
1	R7	6.5k	
1	R8	200	
1	R9	400	
5	J2, RESISTOR NETWORK 1-RESISTOR NETWORK 4	Resistor network Isolated 5x	4.7k Ohm
Capacitors			
23	C1-C3,C7-C25,C31	100n	Ceramic
3	C4-C6	10uF	Tantalum
2	C26,C27	470u	Electrolytic
Integrated Circuits			
1	U1	PIC18F8520	
1	U4	DS18B20	
Miscellaneous			
7	C-ST-E,C-ST-LA, C-ST-NW,C-ST-R, C-ST-RA,JS,SPARE1	3x2 Header 0.1"	
5	E CONTROLLER, LA CONTROLLER, NW CONTROLLER, R CONTROLLER, RA CONTROLLER	A4988	http://www.pololu.com/catalog/product/1182
1	HMI	4x2 Header 0.1"	
1	J4	CONN-H6	Male Header 0.1" for PICKit2 programmer
1	POWER	Power	ED2237
1	POWER LED	LED-Green	
8	PTC1-PTC8	PTC0.25 A Polyfuse	
7	S-E,S-LA,S-NW,S-R, S-RA,SC,SPARE2	2x2 Header 0.1"	

Bill Of Materials
==========
Design: D:\Dropbox\equator_hibu_2012\Proteus\SC 0.2.DSN
Doc. no.: <NONE>
Revision: <NONE>
Author: Ole A. Riiser
Created: 02/09/12
Modified: 05/14/12

QTY	PART-REFS	VALUE	CODE
Resistors			
2	R1,R15	33	
1	R4	18k	
1	R5	3.9k	
2	R11,R16	1.5K	
2	R12,R13	15k	
2	R18,R19	500	
2	R20,R21	6.5k	
1	R23	10k	
Capacitors			
20	C1,C3-C13,C16-C19, C21,C23,C24,C31	100n	Ceramic Type
2	C14,C15	10uF	Tantalum Type
1	C20	1uF	
1	C26	470u	Electrolytic Type(50v)
Integrated Circuits			
1	U1	LPC1768	//LPC Core Board,(from ebay)
1	U2	74HCT365	
1	U3	LM3526	
Transistors			
2	Q1,Q2	BSS138	
Miscellaneous			
6	AIRSPEED,CAN, DISTANCE, MCC 2,MCC 3,STALL	2x2 Header 0.1"	Standard
2	ANALOG HMI,SPARE1	4x2 Header 0.1"	
2	AUTOPILOT,SPARE2,J1	5x2 Header 0.1"	
1	BAROMETER	BAROMETER	BreakOut From sparkFun Electronics (http://www.sparkfun.com/products/9694)
1	DS18B20	DS18B20	
1	GPS1	GPS	Breakoutboard from Sparkfun Electronics (http://www.sparkfun.com/products/10921)
1	IMU1	IMU	Breakoutboard from Sparkfun Electronics (http://www.sparkfun.com/products/10724)
1	J2	5mm-pitch	ED2237
1	J4	USB	
1	LD111733	3.3Volt REgulator	
1	7805CV	5V Regulator	
1	MCC1-ISP	3x2 Header 0.1"	
2	POW LED,USB LINK	LED-GREEN	
8	PTC1-PTC8	PTC 0.25A PolyFuse	
5	RESISTOR NETWORK 1-RESISTOR NETWORK 5	Resistor network Isolated 5x	4.7k Ohm

Visual Paradigm for UML Professional Edition(Buskerud University College)



Visual Paradigm for UML Professional Edition(Buskerud University College)